JOURNAL OF ANIMAL SCIENCE

Published Quarterly

by the

American Society of Animal Production

AUGUST

1942

Volume 1 Number 3

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THE PHYSIOLOGICAL APPROACH TO LIVESTOCK NUTRITION PROBLEMS[1]

L. A. MAYNARD
Cornell University

AT THE outset I should indicate what I mean by this title. I refer to studies of what goes on inside the animal body with a given ration as distinguished from measuring the response merely in terms of increase in weight or product. This involves a consideration of the chemical changes which the nutrients of a feed undergo from ingestion to excretion, and the physiological and biochemical changes of the organs and tissues concerned. It is self-evident that feeding trials under conditions of practice, involving records of the market products obtained, whether meat, milk, wool or eggs, have made large contributions to the improvement of feeding practice. They will continue to be useful, and essential as the final practical test for the results obtained by any other method of experimentation. What further contribution can be made by the physiological approach and what part should it play in our nutrition research of the future? I propose to examine these questions in the light of past accomplishments and of the problems now facing the livestock industry.

The goal of meat production is an economical growth and fattening which will produce the desired carcass quality. Much has been learned about achieving this goal, by physiological studies of modifications of growth which were manifestly uneconomical and otherwise undesirable in practice. Few will recall the work of Waters (1908) (1910), carried out at Missouri, on the capacity of animals to grow under adverse conditions and on the influence of nutrition on size and conformation. But these studies were the forerunners of much later work of practical importance at Missouri and elsewhere dealing with the influence of various nutritional regimes on the development of organs, tissues and other body parts, not measurable in terms of weight and size of the body as a whole.

Three years ago some of you heard McMeekan of New Zealand report briefly before this Society on the growth curve as a means of controlling the conformation and anatomical composition of swine. These extensive and highly significant studies have been published recently as five articles in the Journal of Agricultural Science (McMeekan, 1940, 1941). These papers deserve careful reading by every student of animal husbandry.

McMeekan started with the practical thesis that "the value of any meat

[1] Presented before the Opening Session of the 34th Annual Meetings of the Amer. Soc. of Animal Production. Chicago. Nov. 28, 1941.

animal in any market is dependent basically upon the proportions of the various parts of the carcass and upon its relative composition in terms of bone, muscle, fat and offals." He considered that these characters were controlled by growth and development changes of the body and its parts, differential changes which could be influenced by environmental factors, notably nutrition, as well as by heredity. Hammond (1932) had clearly shown the dependence of conformation and composition of sheep upon growth and development differences. Hammond had also shown in the hog that the maximum rates of growth of the skeleton, muscle and fat occurred at different periods in the growth of the animal as a whole. Following these leads, McMeekan tested the effects of different planes of energy nutrition at the different phases of the growth period, with slaughter and anatomical dissection of the animals. In growing hogs to two hundred pounds, he markedly altered conformation and composition by low and high planes of energy nutrition. More significant, by using both planes—in one case the high for sixteen weeks followed by the low, and in the other case the reverse—two two hundred pound pigs were produced in the same time period with very different proportions of bone, muscle and fat and different organ weights. McMeekan clearly recognizes that his feeding treatments were extreme and not useful in practice as such, but he does conclude that the growth of the whole is a resultant of the differential growth of constituent parts, a growth that can be modified in desired directions by nutrition and that these facts "are important in any study of animal production and fundamental to the study of the meat producing animal."

In the growth and development of breeding stock and animals for milk and wool production our interest goes far beyond the growth period. We are concerned with the development for productive life. Most of you are undoubtedly familiar with the work of McCay *et al.*(1939) (1939a) (1941) at Cornell on the influence of different nutritional regimes on the length of active life, on the development of degenerative diseases, and on longevity. Those who have dismissed the practical significance of these experiments because the longevity has been produced by retarding growth have missed the point. First of all it is significant that dietary changes can influence length of life. More important, a physiological technique has been developed whereby animals of the same age in days, but of very different physiological age, can be comparatively studied and an insight thereby gained into the physiological and pathological changes which are concerned in the decline of physical and mental powers of man and in the productivity of animals. It is significant that the occurrence of tumors, of lung infections and pathological calcification can be influenced by dietary means. The studies have shown that the goal of optimum nutrition is more than the attainment of a

given weight and size, that it should provide for the most efficient performance of the organs and tissues of the body as a whole. There are physiological weaknesses not evident by the ordinary measures of feeding and breeding performance.

Such studies as McMeekan's and McCay's are laborious, expensive and time-consuming. They require the techniques of the chemist, physiologist and pathologist as well as a knowledge as to how to feed animals. They are not for those who would publish a bulletin every year. But they are not to be dismissed as of no practical importance because this importance has not yet been demonstrated. Let us remember that Farady was fifty years in advance of Edison; and Hertz, twenty years ahead of Marconi. Let us see how we can utilize these physiological facts that are being learned in further experiments which may lead to the practical results we seek.

Let us turn to a field, the vitamins, where the practical application to livestock has become clear. It is interesting to note that the first discoveries were made by feeding trials, but feeding trials of a very special character since purified diets were employed—a technique which at the time caused the results to be considered by some to have no application to livestock feeding. The development of the knowledge was slow in the early years because the measures were limited to growth and external changes. It was speeded up when the techniques of the biochemist, physiologist and pathologists were employed to trace the specific functions of the vitamins in the body, and when the organic chemist removed the mystery by identifying them. Twenty years elapsed before vitamin A was identified chemically, but B_6, first recognized as a separate factor in 1934, was isolated in 1938 and synthesized in 1939. Today we appraise vitamin nutrition not in terms of growth productivity or physical appearance, except in extreme cases, but rather in terms of blood studies, functional tests of organs, X-ray examinations and other physiological measures. Such techniques have uncovered the subacute deficiencies which are the more serious in the sense that they are more widespread and long-standing. It is a fruitful field for further work.

Phillips and associates (1938) of the University of Wisconsin reported before this Society that calves on a vitamin A-deficient ration had a low vitamin C as well as a low vitamin A content in the blood. This observation did not arouse much general interest because feeding trials had failed to demonstrate any vitamin C problem in calves. It was known, further, that the C content of cows' milk could not be changed by feeding. But the Wisconsin workers continued their studies. They recalled their earlier work showing a high concentration of vitamin C in the pituitary gland of cattle. They obtained evidence that the concentration of vitamin C in bull semen was related to the potency of the sperm, and that the concentration was fre-

quently low in the blood of "hard to settle" cows. These observations led them to try injections of ascorbic acid into the blood stream of such cows and of bulls of low fertility, with the positive results which you all know from their publications of the last year (Phillips, *et al.*, 1940, 1941). Here are results of practical value which were arrived at from physiological studies of no evident importance at the outset, results which could not have been achieved by feeding trials, for vitamin C is destroyed in the rumen.

Let us examine the physiological basis of the recent findings, with cattle and sheep, regarding the B group of vitamins. About 1850, the French physiologist, Colin, developed the rumen-fistula technique for studying rumen motility. Around 1925 Schalk and Amidon at North Dakota, and Bergman and Dukes at Ames, first made use of the technique in this country. Their work gave Bechdel and associates of Pennsylvania the idea as to how the question whether dairy animals needed vitamin B in their rations might be solved. From feeding trials Theilar and associates (1915) could find no evidence that cows needed this vitamin and suggested that they might synthesize their own vitamins in their digestive tracts. Later, German workers showed that an intestinal organism of herbivora was capable of synthesizing the antineuritic factor. Bechdel and associates (1926) had found that calves would grow normally on rations deficient in vitamin B for rats. It is well known how they fed rumen contents to rats and proved that the synthesis of a growth factor was taking place in the rumen.

But, what was originally thought of as a single factor, proved to be a complex one, and as more B factors were isolated, the question arose as to what factor Bechdel had dealt with. It was ten years later before his technique was used again. In work published within the past two years, McElroy and Goss of California and others have shown thiamin, riboflavin, B_6, nicotinic acid and pantothenic acid are all synthesized in the rumen. Using the purified diet technique, Cornell workers have confirmed the findings for thiamin, riboflavin and nicotinic acid, using calves, lambs and goats, and have added para-aminobenzoic acid to the list.

Certainly physiological techniques have here produced practical results with remarkable speed, but we must not assume that the story is all told. Rather, the results should be emphasized as a starting point for further studies. It has not been shown that rumen synthesis is adequate to meet all body needs and therefore that the dietary supply is of no concern. We know that the extent of the microbiological activity in the rumen is governed by the medium, which in turn is influenced by the nature of the ration of the animal. Under some conditions the supply of B vitamins furnished by rumen synthesis might be adequate; under others, not. We need to apply to ruminants the physiological tests for adequate nutrition of these vitamins under

conditions where they are absent from the diet and under conditions which affect the microbiological activity in the rumen.

Further, in early life the rumen is undeveloped and its functional activity is limited. The first few weeks of the life of the dairy calf particularly needs attention where the feeding of milk is limited and discontinued after a few weeks. Evidence for the importance of such a study has just been furnished by the publication of the results of Phillips, Lundquist and Boyer (1941); indicating that the feeding of certain vitamins of the B group is remarkably effective, along with vitamin A, in curing calf scours. Studies of each vitamin of the B group must be extended to include non-physical symptoms.

The fact that the B group of vitamins is synthesized in the rumen explains why their content in the milk (in so far as studied) is little influenced by feed. We must not consider that this holds for other species. We know the thiamin content of human, rat and guinea pig milk is deficient on a thiamin-low-diet. How about the sow and mare? Again we must not let the absence of recognizable physical symptoms deter us from studying the matter further. Let's see how the animal is functioning inside.

The recent discoveries that hogs require several factors of the B complex emphasize the need for further studies which go beyond a consideration of the physical symptoms obtainable in feeding trials. What are the quantitative requirements for optimum body functions, and what can our common feeds be relied upon to supply? The recent findings of Schultz and co-workers (1941) that different samples of corn, wheat, oats and barley may vary 100% or more in thiamin content, deserve consideration here. Quoting from Hart's (1937) talk before this Society, let us "chart all the factors in nutrition, organic and inorganic, and study their distribution, physiology, pathology and interplay." "Put the need for these factors on a quantitative basis, with optimum allowances for the complete cycle of the animal's life."

The role which the rumen plays in vitamin metabolism reminds us of its role with respect to other nutrients. Zuntz (1891) put forward the suggestion that rumen bacteria might utilize non-protein nitrogen compounds and that this process might play a role in the protein economy of the animal. There followed many feeding experiments in Europe in which a part of the protein of the ration was replaced by urea, ammonium salts, etc. While the more critically conducted experiments suggested that these compounds might spare a part of the protein of the ration, definite proof was not obtained until more exact procedures were employed. Now balance studies of Fingerling, *et al.* (1937) in Germany and of the Wisconsin (Hart, *et al.*, 1939) and Illinois (Harris and Mitchell, 1941, 1941a) workers in this country, have definitely proved that urea and ammonium salts can be utilized by the sheep and cow in covering a part of their protein needs. Using the rumen fistula

method, Studt (1939), in Germany showed that protein was formed in the paunch from amides in the ration and this observation has been confirmed by others. Particularly significant are the studies now in progress at Wisconsin of the conditions in the rumen which govern the extent of this synthetic action and the relation of the nature of the feed supply thereto. It is evident that a new line of physiological investigations has been opened up, having a direct bearing on the concept of "protein quality" and on more economical protein feeding practice.

It has been known for a long time that micro-organisms in the rumen are responsible for the breakdown of the higher carbohydrates. It is now being learned that this process is markedly influenced by feed and other factors governing the process. Thus from the standpoint of protein, carbohydrate and vitamin nutrition, further studies of the microbiology of the rumen are needed and they are highly promising of results of practical value. In selecting rations in the future we are likely to give attention to feeding the bacteria in the rumen as an important phase of feeding the animal itself. In considering the rumen we must not forget the possibility of undesirable processes taking place there also. Ten years ago the Dutch workers Seekles and Sjollema (1932) showed that under certain conditions nitrates were changed to nitrites in the rumen with the consequent formation of methemoglobin in the blood. Wyoming workers (Bradley, *et al.*, 1940) have recently shown that this is the physiological explanation of "oat hay poisoning."

Turning to the field of fat metabolism, the practice of feeding oil cake as a supplement to potatoes for fattening, initiated around 1840, produced beneficial results which were variously explained. Fat rather than protein was first given the credit. Liebig thought that fat could be formed in the body from carbohydrates. Voit insisted that food fat was essential. Lawes and Gilbert (1859) solved the problem by their slaughter experiments which reflected both a thorough knowledge of the science of their day and a sense of how this science could best be used to solve practical problems.

The modern work on the soft pork problem is common knowledge. Studies published within the past year (Hilditch and Pedelty, 1940), by one of science's newest research tools, isotope traces, have suggested a physiological explanation of the "hardening off" of hogs, by showing that fat depots are not inert, but that this fat is constantly being removed and replaced. These studies have given us a new concept of the fat depots which may be of significance in milk production as well.

While broken bones, depraved appetite, and other gross physical symptoms first called our attention to the needs of animals for minerals, bone and blood studies and balance techniques have been the tools by which quanti-

tative needs for all-round optimum nutrition have been established. There is ample evidence of the urgent need for many more of these physiological studies to fill in the gaps of our knowledge of the mineral nutrition of livestock. We were all amazed by the identification of a lack of cobalt as the cause of the losses among grazing animals in Australia, New Zealand and elsewhere, and of the minute amount of the element required to prevent the troubles, Recently, areas of cobalt deficiency have been located in the United States (Baltzer, *et al.*, 1941). Recently also, large areas where copper deficiency is a practical problem have been discovered, apparently involving other physiological functions besides blood regeneration. Additional instances of iron deficiency are being uncovered and manganese, and even magnesium, can no longer be neglected in certain feeding situations.

These recent discoveries regarding mineral elements should teach us several things. In the first place, we cannot rest on the assumption that, aside from salt, calcium, phosphorus and iodine in special situations, commonly fed rations will always meet mineral needs. We know of too many cases where this is not true, and we have learned that the same feed may vary widely in mineral content. More important, these recently discovered cases of mineral deficiency in practice were uncovered where the shortage was bad enough to develop acute physical symptoms which demanded attention. Are there much more widespread cases of deficiencies too mild to be detected by gross observation? Here we should learn a lesson from vitamin research—that the subacute troubles recognizable only by physiological tests, may be the more numerous and the more important.

Taking cobalt as an example, three areas of deficiency in this country have been reported. Are there other feeding situations where this element is of practical importance though hidden because the deficiency is mild? Do we need to take account of cobalt in formulating rations? There are two lines of research for answering these questions: (1) determination of the requirements for optimum body function and an analysis of the food supply in relation to these requirements, or (2) establishment of diagnostic measures of the state of cobalt of nutrition in the body, which can be applied to animals being fed under different conditions and for different purposes. Both of these lines of research require physiological techniques. We must learn first of all how cobalt functions in the body and what organs, tissues and processes are concerned, before we can establish body requirements—for the prevention of physical symptoms is not enough. In carrying out these studies we should hope also to learn of some blood or other test which might measure the state of cobalt nutrition.

With the recent emphasis on vitamin research, the physiology of the mineral elements, particularly the micronutrients, has been, by comparison,

neglected. They need the same detailed attention. It may be that we will come back to the original viewpoint that they are generally unimportant in practice because always supplied in the usual rations, but we need to *know*. Again, what mineral values can we rely upon in "usual" rations these days in view of known soil and other environmental influences, and in view of the changing character of our by-product feeds? In the light of the discoveries already made we are led to wonder to what extent conditions in animals referred to under the general term, "unthriftiness," are due to an undiscovered need of a specific nutrient for a specific physiological function.

In considering specific nutrients, we must not forget that the largest single contribution of feed is energy and that a variety of physiological factors besides digestion determine how much of it is turned into body tissue or product. Physiological studies of the dietary relationships which govern energy utilization, at the Institute of Animal Nutrition and at Illinois, have given us a new concept of balanced rations. Whatever system we use for evaluating feeds in the future, these new discoveries must be taken into account for best feeding practice. They have taught us the importance of dietary interrelations, new examples of which are being uncovered by the physiologist. The influence of the vitamin A intake on the vitamin C economy of the cow has been mentioned. Fat and carbohydrate metabolism are both influenced by thiamin. Important interrelations among the whole group of B vitamins are being uncovered. The physiologist will gradually unravel these complexities and the significant facts can then be translated into feeding practice. In so doing he will make use of a variety of species and a variety of techniques—procedures which have no evident relation to feeding practice. Let us take a lesson from the past, and not think we are wise enough to decide what is practical research and what is not. Paired feeding is, of course, not a procedure for practice, but it has produced information which couldn't have been obtained in any other way. The story is the same for the purified-diet technique and for balance studies.

Other examples of the physiological approach might be described—particularly, perhaps, the contributions of hormone and of blood chemistry studies to our knowledge of milk production. But if I haven't made my point, multiplying examples will not do it. I have tried to show: (1) that feeding practice of today owes much to the physiological studies of yesterday, to laboratory animal experimentation and to a variety of techniques which may have seemed "impractical" at the time, (2) that much remains to be learned regarding the nutrition of the various body processes upon which efficient animal production depends, particularly lifetime performance, and that physiological studies are here required, and (3) that both the practical results thus far achieved and the many questions awaiting solution indicate the

soundness and the promise of the physiological approach to livestock nutrition problems.

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OVULATION AND ITS RELATION TO ESTRUS IN COWS[1]

ANDREW NALBANDOV AND L. E. CASIDA[2]
University of Wisconsin

Introduction

THE most effective use of either artificial insemination or hand mating in the breeding of livestock is possible only if accurate knowledge of the time of ovulation is available. This study was made to determine the variation in the time of ovulation in the cow and to obtain knowledge of the factors affecting the variation.

The time of ovulation in small animals has been determined with much greater accuracy than in the cow because laparotomy can easily be performed on relatively large numbers. Farm animals ovulate just before the end of estrus in most cases. Hammond (1927) finds ovulation occurring in the cow 24 to 48 hours after heat begins. At the Russian Institute of Artificial Insemination (quoted by Hartman, 1939), cows were ovariectomized at various intervals after the beginning of heat and the time of ovulation placed at 48 hours after the onset of estrus. Other estimates of the time of ovulation range between 18 and 30 hours after the beginning of heat (Brewster and Cole, 1941). Since the cow stays in heat for an average of about 16 hours (Hammond, 1927) ovulation would appear to occur after estrus ends.

Experimental Methods and Procedure

Twenty-two grade dairy cows were observed for various lengths of time over a two year period and records on 72 estrual periods were obtained. From two to six estrual periods were studied on 18 of these animals and only one on each of the remainder. Twelve animals showed the color markings of the Holstein Friesian breed, four of the Guernsey breed, and four of the Brown Swiss. Two others could not be characterized.

The cows were checked for heat with a teaser bull (vasectomized or aproned) twice daily, just after the morning milking and again just prior to

[1] Paper from the Department of Genetics (No. 292), Wisconsin Agricultural Experiment Station. This work was supported in part by a grant from the Alumni Research Foundation. The authors wish to acknowledge the assistance of personnel provided by the National Youth Administration and the Work Projects Administration.

[2] Associate Animal Husbandman, Illinois Agricultural Experiment Station, formerly Research Assistant in Genetics, University of Wisconsin and Associate Professor of Genetics, Wisconsin Agricultural E periment Station, respectively.

Data on ovulation and estrus in beef cattle were contributed by J. E. Brewster and C. L. Cole, Dept. of Animal Husbandry, Michigan Agricultural Experiment Station.

Statistical notes are by Churchill Eisenhart, Station Statistician, Wisconsin Agricultural Experiment Station, to whom the authors are also indebted for assistance on other statistical aspects of the study.

the evening milking. When a cow was found in heat checking was continued at as nearly two hour intervals as was practical until she refused to stand. This interval varied to an extreme of four and one-half hours. Every cow was checked for two additional periods after the end of heat to make sure that estrus had ended and also to determine whether "split estrus" found by McKenzie (1939) in mares occurred in cattle. No cases of split estrus were found in the group of animals under consideration.

Soon after commencement of heat a rectal examination of both ovaries was made to determine in which the maturing follicle was located. The size of the follicle and of the ovary and the tone of the follicle and of the uterus also were noted. All measurements were made in "finger-widths," which were then approximated in millimeters. Soon after the end of heat rectal examinations of the ovaries were resumed at approximately two hour intervals (as much as four hours in three cases) until the collapsed follicle indicated that ovulation had occurred. That the frequent palpation of the ovary probably did not hasten ovulation to any appreciable extent is indicated by the fact that attempts to rupture follicles which are physiologically unready for ovulation require a great deal more pressure than was exerted during the routine examination for ovulation. Follicles did rupture at the time of palpation in twelve cases but here it seemed to be a result of the stimulus of touching the ovary rather than of any pressure being applied. The actual time of rupture of the follicle was considered as the time of ovulation in these cases.

The midpoint of the interval between the last check when the cow would accept the male and the first check when she would not was considered as the time that estrus ended. Likewise the time of ovulation, with the exception noted above, was considered as the mid-interval between the last examination when the follicle was present and the first examination when the follicle had collapsed. The total unchecked time, that is, the sum of the two intervals just mentioned, averaged 3,84 hours. This included ten cases of $1\frac{1}{4}$ to 2 hours, fifteen of 3 to $3\frac{3}{4}$, twenty-one of 4, eighteen of $4\frac{1}{4}$ to 5 and four of $5\frac{1}{2}$ to $6\frac{1}{2}$ hours. The maximum error in determining the interval from end of heat to ovulation would be one-half of the above values.

Observations on the Process of Ovulation

The follicle increases markedly in size beginning late in the heat period. This is accompanied by rather marked protrusion from the surface of the ovary. Shortly before ovulation, the wall of the follicle seems to become thinner and the follicle feels more pliable and soft to the touch. This softening of the follicle, however, does not invariably mean that ovulation is impending as some follicles again become turgid followed by a second phase of softening just before ovulation.

In many cases it appears that all of the follicular fluid does not escape at the time of ovulation. That is, upon subsequent examination the follicle will be partially collapsed but a small amount of fluid remains in it and this escapes when a slight pressure is exerted on the surface. These observations give the impression that the bursting of the follicle is in reality a gradual process in the cow. There is, of course, a possibility that this residual fluid is blood resulting from intrafollicular hemorrhage associated with ovulation.

It was noted above that in 12 cases follicles ruptured at the time of palpation. Here the follicles were much larger than usual, sometimes as much as 30 mm. in diameter. These cases, which would represent a few more than 20% of the observations, may be aberrant and not at all typical of the normal ovulation process.

Analysis of Data

Two sets of data will be presented. Concurrent experiments were carried on at the Wisconsin Agricultural Experiment Station and at the Michigan Agricultural Experiment Station. The work was planned by the two groups of observers so that the two sets of data could be combined for analysis. A brief report of the Michigan study has already been presented by Brewster and Cole (1941). Emphasis will be placed, therefore, upon the analysis of the Wisconsin dairy cows but comparisons will be made with the Michigan data on beef cows. Three types of data are available from the studies made. These include variation in the time that estrus ends, variation in the time of ovulation, and variation in the length of the interval from the end of estrus to ovulation (Table 1).

The time that estrus ends will be spoken of as the "lateness" of the end of estrus. It has been measured on a relative basis. The day that estrus began has been taken as the starting point, and the earliest hour in the day at which any cow in the entire herd went out of heat as hour-1. This hour was noon in the Wisconsin Herd and 4:00 P.M. in the Michigan Herd. The "lateness" with which any estrual period ended also has been measured on an ascending scale from hour-1. In calculating the lateness of ovulation, the day that estrus began has again been used as the starting point. The earliest hour for all cows in the herd at which any cow ovulated with respect to the day that she began her estrual period was midnight in the Wisconsin Herd and 10:00 P.M. in the Michigan Herd. These constitute hour-1 in the respective groups of animals and variation is measured on an ascending scale from these hours. For example a cow in the Wisconsin Herd going out of heat at 5:00 P.M. of the day first noted in estrus and ovulating the next morning at 6 o'clock would be measured as 6 for lateness of end of heat and 7 for lateness of ovulation. The same cow in the Michigan Herd would be measured as 2

TABLE 1.—FREQUENCY DISTRIBUTIONS AND MEANS OF DATA ON END OF ESTRUS, OVULATION AND LENGTH OF INTERVENING INTERVAL

Number of hours	Dairy cows (Wisconsin)			Beef cows (Michigan)		
	Interval —end of estrus to ovulation	Lateness —end of estrus (noon-hr.—1)	Lateness of ovulation (midnight =hr.—1)	Interval —end of estrus to ovulation	Lateness —end of estrus (4 PM= hr.—1)	Lateness of ovulation (10 PM= hr.—1)
1–2	1	2	1	0	2	1
3–4	1	2	0	0	7	0
5–6	0	12	2	2	7	0
7–8	2	14	18	1	7	0
9–10	6	9	7	0	10	1
11–12	12	7	8	8	4	7
13–14	17	8	12	8	2	5
15–16	11	7	9	11	0	5
17–18	9	5	5	6	0	11
19–20	5	2	3	1	1	5
21–22	4	0	2	2	0	1
23–24	0	0	1	1*	0	4
Mean	14.16	9.87	12.03	14.62	7.53	16.15
Total estrual periods	68	68	68	40	40	40

* 26 hrs.

and 9 respectively. Recordings were made in central standard time at Madison, Wisconsin, and eastern standard time at East Lansing, Michigan.

In 68 of the 72 estrual periods which were observed on dairy cattle, ovulation occurred within 22 hours after the end of estrus (Table 1). Ovulation was delayed until sometime between 47 and 104 hours after the end of estrus in two other cases and in two cases the follicle regressed without ovulation taking place. Ovulation occurred by 26 hours after the end of estrus in the 40 estrual periods of beef cattle that have been studied. Two estrual periods of one animal, however, have been omitted because in that case ovulation occurred during estrus. No cases were observed in which ovulation occurred during estrus with the dairy cattle. The mean intervals between end of estrus and ovulation, 14.16 and 14.62 hours for the dairy cows and beef cows, respectively, are in very close agreement.

Variation in the length of interval from the end of estrus to ovulation is brought about by variation in the time of day that estrus ends and the time of day that ovulation occurs. The average time of day at which the dairy cows went out of estrus was 8:52 P.M. on the day they were first noted in estrus.

The average time of day for the end of heat with the beef cattle was 10:32 P.M. The average time of ovulation was 11:02 A.M. for the dairy cows and 1:09 P.M. for the beef cows, both occurring on the day following the time when the cows were initially noted in heat.

The observed distributions of the data for both time of termination of estrus and time of ovulation are markedly different from those expected on the supposition that the events are equally likely to occur at any hour during the 24 hour day. Estrus terminated in 57 of the 68 cases of dairy cattle between 4:00 P.M. on the day they were first noted in heat and 4:00 A.M. the following morning (Table 1). Likewise, 37 of the 40 estrual periods of beef cattle terminated between 4:00 P.M. and 4:00 A.M. In contrast so far as time of day is concerned ovulation occurred in 59 of 68 cases with the dairy cattle and in 34 out of 40 cases with the beef cattle between 6:00 A.M. and 6:00 P.M. on the day following the time they were first observed in heat. The probability of at least one selected 12-hour interval out of a time cycle of 24 hours showing as high a proportion of the cases as indicated in any one of the four instances just mentioned is much less than 0.001 on the hypothesis that the event is equally likely to occur at any time during the 24-hour day.[3] From this it seems safe to infer that termination of estrus in a majority of cases will occur between 4:00 P.M. of the day heat begins and 4:00 A.M. the next morning and that ovulation will occur in a majority of cases between 6:00 A.M. and 6:00 P.M. of the next day. It is doubtful if a more specific statement should be made because respective cows contributed different amounts of information and it is difficult to make due allowance for cow individualities.

Although there was no attempt to get at the precise time at which estrus began, some variation in the time for beginning of estrus could be noted from checking the cows only twice daily. In 54 of 68 estrual periods on dairy cows, estrus was first noted in the morning; in 14 cases it appeared during the afternoon.

In 11 of the dairy cattle estrus was first noted in the morning on some oc-

[3] *Refutation of the Equal-Probability Hypotheses.* The facts and mathematical basis for the statement in this sentence are: (a) Since the data are given in table 1 in 2-hour class intervals, there are only 6 *different* dichotomies of the 24-hour day—there are 12 ways altogether but among these are pairs which are equivalent, being mirror images of one another. (b) If P denotes the probability of an arbitrary one of these dichotomies possessing a certain property, then $(1-P)^6$ expresses the probability of *none* of the 6 different dichotomies possessing this property, so that $1-(1-P)^6 = 6P-15P^2+20P^3- \ldots = 6P$, approximately for small P, is the probability of *at least one* of these 6 different dichotomies possessing the property in question. (c) The "property" of a dichotomy considered here consists of its yielding a χ^2 in excess of 14.176, *this χ^2 being calculated on the supposition of equal expected frequencies* for the two halves of the 24-hour period determined by the dichotomy. The probability of *an arbitrary* dichotomy yielding a χ^2 in excess of 14.176 is $\frac{1}{6}$ (.001) *on the hypothesis of equal expected frequencies*, and, therefore, from (b) the probability of *at least one* of the six yielding such a χ^2 is .001 on this hypothesis. Accordingly, the χ^2 corresponding to the dichotomy with the greatest inequality of observed frequencies can be judged significant at the .001 level whenever it exceeds 14.176. (d) It is easy to verify that the dichotomies mentioned in the text yield χ^2 values of 31.12, 28.90, 36.76, and 19.60 respectively. Since each of these exceeds 14.176 by a good margin the statement quoted follows.

TABLE 2.—EFFECT OF TIME OF DAY AT WHICH ESTRUS WAS FIRST NOTED

Item studied	d.f.	Lateness of estrus			Lateness of ovulation			Interval from end of estrus to ovulation		
(A) *Variation*		mean square	*F*	P	mean square	*F*	P	mean square	*F*	P
Between times	1	84.34	5.52	.030	29.88	2.67	.119	13.81	.709	.411
Interaction	20	13.72			9.04			16.50		
Error	19	15.28			11.18			19.48		
Total	30									
PM mean—AM mean		3.15 hrs.			1.87 hrs.			−1.28 hrs.		
(B) *Variation*	d.f.	mean square	*F*	P	mean square	*F*	P	mean square	*F*	P
Between times	1	109.23	4.31	.065	55.21	2.45	.149	9.13	3.48	.092
Error	10	25.35			22.51			2.62		
PM mean—AM mean		7.68 hrs.			5.46 hrs.			−2.22 hrs.		
(C) Combination of evidence*		$P' \leq .0043$			$P' \leq .029$			$P' \leq .054$		

* In analysis C the information provided by analyses A and B is combined to provide a single probability, the probability given being that appropriate to testing (1) the null hypothesis "PM mean not greater than AM mean" in the cases of the data on lateness of estrus and on lateness of ovulation, and (2) the null hypothesis that "PM mean not less than AM mean" in the case of data on interval from end of estrus to ovulation. That is, P' given in C is obtained by halving the probabilities given in A and B, and then combining these by the method of sec. 21.1 of R. A. Fisher's "Statistical Methods for Research Workers." For this purpose the actual probability of obtaining (when the hypothesis tested is true) an F value at least as large as that observed is needed, and not merely whether F exceeds its 5% or 1% significance level. This probability can be obtained by noting that

$$\text{Probability of an } F \text{ not less than } F_0 = 1 - I_x(p, q)$$

for $x = n_2/(n_2 + n_1F_0)$, $p = \frac{1}{2}n_2$, and $q = \frac{1}{2}n_1$, where F_0 denotes the observed value of F, n_1 and n_2 the degrees of freedom of the numerator and denominator of F respectively, and $I_x(p, q)$ is the function tabulated in table I of *Tables of the Incomplete Beta-Function* (edited by Karl Pearson, University College, London, 1934). The values of P shown in parts A and B of table 2 were obtained in this manner, as were also the values of P shown in table 3.

casions and in the afternoon on others. Of the 41 estrual periods provided by these cows, estrus was first noted in the morning in 29 cases and in the afternoon in 12 cases. When these cows were not noted in heat until the afternoon the end of the heat period was delayed on the average 3.15 hrs., the occurrence of ovulation was delayed 1.87 hrs. on the average, and the interval between end of heat and occurrence of ovulation was decreased 1.28 hrs. on the average (Table 2:A). Of these only the first is statistically significant considered alone. The other 11 dairy cows were first noted in heat either in the morning or in the afternoon on all occasions. These cows provided 27 estrual periods, in 25 of which estrus was first noted in the morning. The two cows which were first noted in estrus in the afternoon only terminated estrus 7.68 hrs. later on the average, ovulated 5.46 hrs. later on the average, and had a shorter interval from end of estrus to ovulation by 2.22 hrs. on the average than the cows first noted in heat in the morning only

TABLE 3.—DIFFERENCES BETWEEN COWS

Item studied	Lateness of end of estrus	Lateness of ovulation	Interval from end of estrus to ovulation
Number of cows	17	17	17
Number of estrual periods	63	63	63
Total variance	19.45	19.27	16.50
Between cow mean square	27.81	37.69	23.62
Within cow mean square	16.54	12.87	14.02
F	1.681	2.93	1.685
P	0.085	0.002	0.085
Deduced intra-cow correlation*	(0.17)	0.37	(0.18)

* *Intra-Class Correlations.* Since the 17 cows providing the data upon which table 3 is based contributed unequal numbers of observations, a slight modification of the customary method of calculating intra-class coefficients was necessary here. Denoting by A the estimated variance between classes (cows), and by B the estimated variance within classes (here, between observations on a single cow), the intra-class correlation coefficient can be expressed (R. A. Fisher: *Statistical Methods for Research Workers*, sec. 40) as

$$\rho = \frac{A}{A+B}.$$

To evaluate A and B from an analysis of variance table when the numbers of observations $n_1, n_2, \ldots, n_k$ in the respective classes are not all the same it suffices to note that

$$\text{Between classes mean square} = n_H A + B$$
$$\text{Within classes mean square} = B$$

where $n_H = k / \Sigma\,(1/n_i)$ is the *harmonic mean* of the n's. When the n's are all equal, n_H is their common value, and the above reduces to the customary procedure. The intra-class correlations shown were calculated in this manner, n_H for these data being 3.218. The two values given in parenthesis are not statistically significant at the 5% level of significance, as the P values show, but they are bordering on significance, so it seemed advisable to indicate their values and to refrain from drawing inferences from them for the present.

(Table 2:B). Combining the probability evidence from these separate analyses (Table 2:C) it appears that when estrus was not apparent until the afternoon, termination of estrus and occurrence of ovulation were both *delayed* to a statistically significant extent ($P \leqq .004$) ($P \leqq .029$), and the interval from end of heat to ovulation was diminished by an amount bordering on statistical significance ($P \leqq .054$).

This comparison was available only on the dairy cows. Most of the cows first noted in heat in the afternoon were out of heat by the next morning, which would interfere with natural mating at that time. Furthermore these cases were not consistently late enough in ovulation so that artificial insemination could be delayed safely until the next morning.

There were 17 of the dairy cows for which there were records of two or more estrual periods. This made it possible to study the data from the standpoint of repeatability. Analysis of variance showed there was a significantly greater difference between cows in the lateness of ovulation than there was between different estrual periods of the same cow, 37% of the total variation in lateness of ovulation being due to cow differences (Table 3). There

TABLE 4.—SIMPLE CORRELATIONS SHOWING INTERRELATIONS OF PHENOMENA ASSOCIATED WITH TIME OF OVULATION

Item studied	Interval end of heat to ovulation and hr. of end of heat	Interval end of heat to ovulation and hr. of ovulation	Hr. of end of heat and hr. of ovulation
Michigan beef cows*			
Total	−0.33	0.60	0.55
Wisconsin dairy cows**			
Total	−0.46	0.46	0.57
Within cows	−0.58	0.38	0.53
Between cows	−0.28	0.57	0.65

* 18 cows with 1 heat period each, 7 with 2, 1 with 3, and 1 with 5.
** 5 cows with 2 heat periods each, 1 with 3, 5 with 4, and 6 with 5.

was only a suspicion, however, of cow differences in lateness of end of estrus and interval from end of estrus to ovulation.

Among the various inter-relations of phenomena associated with time of ovulation it is to be noted that the later the hour at which estrus ended the shorter was the interval between the end of estrus and ovulation. Also, the later the hour of ovulation the longer was the interval between the end of estrus and ovulation, and the later the hour that estrus ended the later also was the hour of ovulation (Table 4). These generalizations appeared to hold for both the beef cows and the dairy cows. The data for the latter were of such a nature that these correlations could be measured both within cows and between cows. The associations between the hour that estrus ended and the hour of ovulation were probably not unlike within cows and between cows. The effect of the inherent repeatability of the hour of ovulation shows up in the other two correlations. The between-cow associations of the hour of ovulation and the interval from end of estrus to ovulation was greater between than within cows. It was pointed out above that individuality was questionable with regard to the lateness of end of heat and this may be reflected in its greater association with interval length for the within-cows than for the between cows. The measure of total covariance for the various inter-related phenomena on the beef cows is more comparable to the between-cow covariance on the dairy cows. This arises from the fact that the greater proportion of the data on beef cows represented a single set of observations on each cow. There is a marked similarity between the correlations, −0.33 as compared to −0.28, 0.60 compared to 0.57, and 0.55 as compared to 0.65.

Discussion

The cattle used in these studies have shown a marked tendency for ovulation to occur after the end of estrus. In only two of a total of 114 cases did

ovulation occur during estrus. This is in contrast to known conditions existing in other farm animals where ovulation occurs more frequently during estrus. The average interval from estrus to ovulation was very similar for beef cattle and dairy cattle.

Mating or insemination during the afternoon of the day of heat would probably be better than mating in the morning. It is expected that this practice would find most of the cows still in estrus and would give ample time for the sperm cells to reach the oviduct by the time the egg would be available for fertilization. Brewster, May and Cole (1940) suggest that the time for sperm to reach the infundibulum in the mature cow will range between 6 and 9 hours. It is also expected that the interval during which potential fertility of the sperm persists (Hammond and Asdell, 1926, and Soderwall and Young, 1940) would insure fertilization for a period beyond the time of ovulation.

The question has often been raised whether cows first noted in heat in the afternoon should be mated at that time or delayed until the next morning. The data presented in this paper have to do only with cows coming in heat in the afternoon and not for those coming into heat in the evening. Hand-mating for the afternoon cases, however, would be difficult if delayed until the next morning for the majority of these animals were out of estrus at that time. Artificial insemination, could be practiced but here again a question should be raised with regard to the time of ovulation. The timing would appear to be proper in most of the cases if insemination were done very early the next morning but later in the morning would likely be undesirable.

The time of ovulation appeared to be an inherent characteristic of a cow. This may be a hereditary characteristic but it may also be due to environmental factors acting upon cows differently during a period from a few weeks to a few months corresponding to the length of time over which the observations were made on any one cow. All of the cows studied were not present within the herd at any one time. The general program of feeding and herd management was not known to vary appreciably during the course of these observations but there were changes in season, feed source, etc. These cows came from various sources and there is no history of the individuals prior to the time that they were used in this experiment. These factors could exert "permanent" environmental effects as far as these observations are concerned.

Summary

A total of 72 estrual periods on 22 grade dairy cows were studied. The following findings are reported:

(1). Ovulation occurred approximately 14 hours after the end of estrus.

(2). The mean time of day for estrus to end was between 8 and 9 o'clock in the evening.

(3). The mean time of ovulation was approximately 11 o'clock in the morning.

(4). Differences were detectable in the times of termination of estrus and of ovulation for cows first noted in heat in the afternoon and those first noted in heat in the morning. There is a slight indication that the interval from end of estrus to ovulation may be slightly shorter.

(5). Thirty seven per cent of the total variation in time of ovulation was attributable to differences between cows.

(6). The later the hour that heat ended the shorter the interval from the end of heat to ovulation ($r = -0.46$).

(7). The later the hour of ovulation the longer the interval from the end of heat to ovulation ($r = 0.46$)

(8). The later the hour that heat ended the later was the hour of ovulation ($r = 0.57$).

A marked similarity exists in the means, the variation and the interrelations of the different phenomena associated with ovulation for the dairy cattle studied at the Wisconsin Station and the beef cattle studied at the Michigan Station.

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THE EFFECT OF THE METHOD OF MAKING SEMEN SMEARS UPON THE NUMBER OF MORPHOLOGICALLY ABNORMAL SPERMATOZOA

G. W. Salisbury, E. L. Willett[1] and Jack Seligman
Cornell University[2]

THE determination of the number of morphologically abnormal spermatozoa in a sample of semen is widely used as a diagnostic aid in identifying certain cases of male sterility, both in man and the lower animals. It is stated that reliable estimates may be made of the potential fertility of males by this means. Williams and Kingsbury (1920), Williams and Savage (1925), Mason (1929), Moench and coworkers (1930, 1931), and McKenzie and Phillips (1933, 1934) have all emphasized the importance of this technique in the assay of potential male fertility.

In investigations of bull semen, however, we have noted a wide variability in the counts of certain types of morphologically abnormal spermatozoa. This fact appeared to be true not only with respect to different bulls but also appeared to be associated with the manner in which the semen was handled during and after collection and the techniques employed in the preparation of the slides for staining.

The question arises as to whether the variability noted was due to an inherent difference in the samples of semen examined or whether the methods of handling and methods of preparation of slides were responsible for the variability. It is obvious that the answer to this question is of importance in connection with the assay of the potential fertility of a male. Consequently an experiment was designed to determine insofar as possible the effect of the method of preparation of semen smears upon the number of abnormally formed spermatozoa.

Procedure

Eleven different ejaculates were collected by means of the artificial vagina from seven different bulls, five of known high reproductive efficiency and two with poor reproductive records. All samples were handled in a comparable manner, though no particular attention was paid to the details of temperature control during the preparation of the slides. Willett (1941) has shown that rapid cooling has a marked influence on the number of spermatozoa with the tails coiled about the head. This fact is probably responsible for the high proportion of such types observed in this study. Two samples,

[1] Now Animal Husbandman, Agricultural Experiment Station, Rio Piedras, Puerto Rico.
[2] Department of Animal Husbandry, Ithaca, N. Y.

taken about a week apart, were collected from each of four bulls. A single sample was obtained from each of the other three bulls.

Semen smears were made by four different methods, the first two of which are standard practice with many investigators. The other two were developed for this experiment with the thought that they might produce more satisfactory results than the others employed. In order to identify more clearly the varying morphological characteristics of the spermatozoa in the stained slides, it was necessary to dilute each sample at the rate of one drop semen to 1 ml. of Milovanov's (1933) SGC-2 diluter. The four methods employed were:

1. A small drop of the diluted semen was placed on a clean microscopic slide. Another clean slide was placed flatly down on the slide containing the semen and pulled along on it with a smooth even motion. The lower slide was allowed to dry and was later prepared for staining.

2. With one slide flat on the desk and the second held at approximately a 45° angle with it, a drop of diluted semen was placed at the base of the second slide and pulled behind it along the first. The latter slide was allowed to dry at room temperature.

3. A small drop of the diluted semen was placed on a slide and was gently spread over it, using straight smooth strokes with a dry, fine camel's hair brush.

4. 0.01 ml. of semen was added to 2.0 ml. of the diluter in a small test tube and gently mixed by slowly turning the tube end over end until the mixture was homogeneous in appearance. The contents of the tube then were poured gently onto a slide and allowed to dry. Much of the contents of the tube actually poured over the side of the slide in the process.

The following staining technique was used:

1. The slides were cleared by immersion for about 5 minutes in a 1.0 per cent solution of chlorazene, rinsed in tap water, and dried rapidly under an electric fan.

2. They were stained for 45 seconds in Ziehl's carbol fuchsin, washed thoroughly in tap water, and dried under the fan. The slides were then counter-stained for 45 seconds in aniline gentian violet, washed in tap water and again dried. In comparison with other staining methods and other stains studied by us this procedure has proven to be the easiest as well as giving the best delineation of cellular outline.

Classification and Counting of Morphologically Abnormal Spermatozoa

Each stained slide was placed on a movable microscope stage and following a standard technique of moving the slide about, approximately 550 indi-

vidual spermatozoa were examined and classified as to morphological type. It was originally planned to count but 500 spermatozoa. However, when the examination of all slides had been completed it was found that the number counted had varied from 506 to 605 spermatozoa. This introduced a variable which necessitated statistical control in the analysis of the data.

The spermatozoa were classified into the following groups:

1. Morphologically normal.
2. True abnormals, which included such types as those possessing any abnormality with respect to the shape or size of the head, spermatozoa with enlarged, abaxial, beaded or filiform middle pieces, and those with thickened or double tails.
3. Tailless spermatozoa.
4. Spermatozoa with broken necks.
5. Spermatozoa with coiled tails.

The counts obtained expressed in percentage are given in table 1. An examination of this table shows considerable variability in the data. This is true especially with respect to the difference found between the third method of making the semen smears and the other three methods. However, for confident evaluation a more powerful tool for picking out differences in such data and for showing that such differences cannot reasonably be attributed to chance must be used.

Methods and Results of Statistical Analysis

Since an equal number of spermatozoa had not been counted on each slide it was impossible to use the total number of spermatozoa recorded in each classification for the analysis. The method which seemed to introduce the least difficulty was to calculate the percentage of each type of abnormality observed and transpose these data into equivalent angles after the method of Bliss (Snedecor, 1940). The method of the analysis of variance was used to test the significance of the differences noted between ejaculates, between bulls, between ejaculates of the same bull, and between the methods of preparing the smears. The levels of probability of $P \leqq .05$ and $P \leqq .01$ were considered as significant and highly significant, respectively. When studying the variability between bulls and between ejaculates of the same bull the error term was calculated from the eight ejaculates produced by the four bulls from each of which two ejaculates had been taken.

Probability values (P) for differences between the means of the 4 methods of preparing the smears and for differences between the means of bulls with two ejaculates are given in table 2. These data show that the method used in making the smears has a significant effect upon three of the classifications of abnormal spermatozoon types. For the true abnormals, method 4 produced

TABLE 1.—PERCENTAGE OF SEVERAL TYPES OF MORPHOLOGICALLY ABNORMAL SPERMATOZOA COUNTED IN ELEVEN EJACULATES PREPARED BY FOUR DIFFERENT METHODS

Bull	Ejaculate	Total true abnormals				Tailless heads				Broken necks				Coiled tails			
		Method				Method				Method				Method			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	1	6.9	6.6	7.9	8.7	3.8	4.7	34.5	6.4	11.9	3.8	8.3	9.5	42.6	52.3	31.6	45.9
	2	4.6	2.5	4.6	6.4	3.3	1.7	29.8	5.8	11.7	18.8	10.4	4.1	37.9	48.6	29.1	32.5
2	1	5.3	5.9	6.6	7.8	3.1	4.4	31.6	8.1	7.7	5.4	6.8	6.7	48.4	53.5	35.8	55.0
	2	7.0	7.4	7.0	7.6	6.4	7.4	40.3	8.0	2.3	8.2	0.6	1.3	34.9	35.7	12.2	35.0
3	1	4.6	5.5	4.1	6.3	13.2	11.3	23.9	20.0	3.9	7.7	1.7	6.5	32.5	39.1	34.0	36.8
	2	5.4	7.0	6.2	6.0	8.6	6.8	30.0	6.0	16.3	11.2	5.8	5.2	34.1	37.3	23.3	8.7
4	1	6.3	7.6	8.7	7.9	7.5	4.7	26.5	4.6	1.2	2.3	2.7	0.6	76.8	70.9	47.7	72.9
	2	8.5	8.3	7.8	8.8	2.1	4.7	13.6	4.9	2.8	3.2	11.1	1.2	76.1	70.2	55.2	71.1
5	1	18.2	19.4	16.9	19.1	4.1	4.7	15.4	3.9	0.7	0.4	1.5	1.1	45.3	30.6	32.2	50.5
6	1	6.0	6.6	5.1	7.6	2.2	2.5	18.8	4.9	0.5	2.0	2.8	3.4	57.6	52.1	44.2	50.4
7	1	6.1	8.0	6.8	7.9	6.5	11.8	20.3	7.5	1.9	0.4	3.0	1.1	40.2	26.6	21.1	29.9
	Average	7.2	7.7	7.4	8.7	5.5	5.9	25.9	7.3	5.6	5.8	5.0	3.7	47.9	47.0	33.3	41.2

significantly higher counts. This fact may be due to mechanical removal from the slide of true abnormal types by the three other methods employed. Method 3 produced an unduly high proportion of tailless heads and a significantly lower proportion of coiled tails. Both of these results are probably due to mechanical effects of the camel's hair brush. Why no difference was found between treatments in the proportion of spermatozoa with broken necks is difficult to understand when there was a highly significant difference between treatments for tailless heads.

TABLE 2.—P VALUES FOR TESTS OF SIGNIFICANCE OF DIFFERENCES BETWEEN MEANS OF FOUR METHODS OF PREPARING SMEARS FOR ALL EJACULATES AND DIFFERENCES BETWEEN MEANS OF FOUR BULLS WITH TWO EJACULATES

Treatment comparisons	True abnormals	Tailless heads	Broken necks	Coiled tails	Bull comparisons	True abnormals	Tailless heads	Broken necks	Coiled tails
	P	P	P	P		P	P	P	P
1 & 2	>.05	>.05	>.05	>.05	1 & 2	<.05	>.05	<.05	>.05
1 & 3	>.05	<.01	>.05	<.01	1 & 3	>.05	<.05	>.05	<.05
1 & 4	<.01	>.05	>.05	>.05	1 & 4	<.01	>.05	<.01	<.01
2 & 3	>.05	<.01	>.05	<.01	2 & 3	<.05	>.05	>.05	<.05
2 & 4	<.05	>.05	>.05	>.05	2 & 4	<.05	<.05	>.05	<.01
3 & 4	<.01	<.01	>.05	<.01	3 & 4	<.01	<.01	<.05	<.01

The *P* values given in the table also emphasize the fact that there are not only significant differences between bulls with respect to the proportion of true abnormal types, but, also, significant differences between bulls with respect to the effect of preparation of the smear on the proportion of other types of abnormalities. Obviously, the proportion of tailless heads and sperm with coiled tails is influenced by the method of preparation of the smear, and in some measure may be considered as artifacts. Nevertheless, semen from different bulls reacted differently to the treatments used. This fact emphasizes the importance of carefully controlled standard conditions of handling semen if comparisons of males are to be made and any attention is to be paid the types of abnormalities observed other than what we have classified as the true abnormals. This is especially true of the type having coiled tails. In this investigation we desired to produce a certain proportion of spermatozoa of this type but did not intend to overdo it as it appears we have done. In later investigations under carefully controlled conditions of drying so as not to subject the spermatozoa to temperature shock we have made slides containing a much lower proportion of coiled tails.

In a comparison of the first and second ejaculates from each of the four

bulls it is of interest to note that a significant difference was found in the proportion of true abnormals only between the first and second ejaculates of bull number 1. The *P* value for this difference was $<.01$. No differences were found between ejaculates of any of the bulls for the tailless heads or spermatozoa with broken necks. However, for the proportion of coiled tails a highly significant difference was found between the first and second ejaculates of bull 2. A significant difference between ejaculates of bull 3 for this classification was also found. This may have been due to a difference in treatment of the semen before smears were made or to an actual difference between resistance of the spermatozoa to treatment.

That a greater variability between first and second ejaculates from the same bull was not observed was encouraging for it indicated that within reasonable limits the proportion of abnormals in the semen of a bull tends to remain constant. However, the fact that the proportion of true abnormals varied significantly between the first and second ejaculates of one bull and the proportion of coiled tails differed significantly between the first and second ejaculates of two other bulls is sufficient to indicate that caution must be used in diagnosing sterility on the basis of the examination of one ejaculate.

In this connection it is interesting to note that of the two bulls with poor breeding records, Nos. 5 and 6, only one (5) produced semen with a high enough proportion of true abnormal spermatozoa to be classified as sterile. The other bull produced a low proportion of true abnormals. This bull has been shown to produce semen possessing large numbers of *Pseudomonas pyocyaneus* which apparently indicates an infection of the genital tract (Gunsalus, Salisbury and Willett, 1941).

Summary and Conclusions

Considering all factors involved in this study it would appear that the most satisfactory method to be used in the preparation of semen smears is that in which a drop of diluted semen is spread over a clean slide by simply placing another clean slide face down on it and pulling the two apart lengthways. Apparently the film of liquid between the two slides is sufficiently thick to protect the individual spermatozoa if undue pressure is not applied.

This study emphasizes the importance of a standard procedure in the handling of semen and in the preparation and staining of slides when two or more males are to be compared with the view to assessing their relative fertility. It also shows that while tailless heads and spermatozoa with coiled tails, at least in some cases, may be considered to be artifacts, as the proportion of these types of abnormalities may be influenced by the method of treatment, the semen of individual males varies with respect to its resistance to these treatments.

Finally, this study emphasizes the necessity of examining more than one sample of semen from a male when the proportion of morphologically abnormal spermatozoa alone is used as the criterion of fertility.

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THE INFLUENCE OF INBREEDING ON BIRTH WEIGHT, RATE OF GROWTH, AND TYPE OF DAIRY CATTLE[1]

J. W. Bartlett, R. P. Reece and O. L. Lepard
New Jersey Agricultural Experiment Station

Introduction

A CONSIDERABLE amount of research work has been conducted with laboratory animals in an attempt to determine the effect of inbreeding on growth rate. Few results, however, have been reported showing the influence of inbreeding on size at birth, rate of growth, and type of dairy cattle.

Woodward and Graves (1933) inbred cattle to determine whether a good dairy herd could be bred from an ordinary one by use of only one good bull. Grade cows were bred to either a registered Guernsey or a registered Holstein-Friesian bull and the daughters were bred back to their sires for successive generations. With the Guernsey bull the inbreeding was limited to two generations of daughters. The Holstein-Friesian experiment was carried on through several generations of inbred sons and grandsons of the foundation sire as well as daughters of these sires. The results of the Guernsey experiment showed that the birth weights of the calves decreased as inbreeding became more intense. A few inbred calves were deformed at birth. The mature weights of the cows were reduced by inbreeding. The results of the Holstein-Friesian experiment indicated that the birth weights of the more intensely inbred calves were reduced to a marked extent. Intensive inbreeding appeared to decrease the rate of growth. In a preliminary report Bartlett, Reece and Mixner (1939) concluded that dairy cattle could be inbred successfully provided a rigid system of selection was followed. If inbreeding resulted in inferior animals this was not caused by the system of mating but by the mating of genetically inferior animals. For example, inbreeding directed toward Ormsby Sensation 45th 442551 proved successful. On the other hand when inbreeding was practiced with the King Bess Beulah De Kol Ormsby family a lethal factor caused the death of many of the offspring either at birth or shortly thereafter. Two cases of the lethal recessive factor "Bulldog" appeared in the F_2 generation. Various malformations of the reproductive organs were observed. Growth rates of inbred heifers were not significantly different from growth rates of outbred heifers. Dickerson (1940) re-

[1] Journal Series Paper of the New Jersey Agricultural Experiment Station, Rutgers University, Department of Dairy Husbandry, New Brunswick, N. J.

ported that calves averaging 16 per cent inbred averaged nearly 10 per cent lighter at birth than outbred calves by the same sires. It appeared that the size difference in favor of the outbreds became proportionately smaller rather than larger with growth up to 6 months of age.

The results reported in this paper were obtained from the project on inbreeding and outbreeding Holstein-Friesian cattle in an attempt to establish genetic factors for high milk production and high fat test now in progress at this station.

Material and Methods

The foundation animals included 45 Holstein-Friesian cows selected in New England, New York, and New Jersey on the basis of normal size, good type, and mature equivalent class C fat production of 480 pounds with the milk testing at least 3.6 per cent butterfat. Four bulls were selected as foundation sires at the beginning of the experiment.

Progeny of the foundation animals were mated as follows: (a) sire-daughter matings; (b) brother-sister matings; (c) matings with less than 50 per cent of the same blood, and (d) outbreeding. The last system of mating has furnished adequate controls for the inbreeding experiment. Of the inbred animals now in the herd, a great majority are the result of mating descendants of one of the foundation sires, Ormsby Sensation 45th 442551.

In June, 1935, all females in the breeding experiment were weighed and measured for height at the withers and for circumference of chest. Measurements and weights were taken monthly until the animals were 10 months old. Subsequent measurements and weights were taken on females at intervals of 3 months. First-calf heifers and older animals were also weighed and measured 3 weeks before they were due to calve and 3 weeks after calving.

Heifers, while on pasture, have been classified as to type by a committee composed of members of the Department of Dairy Husbandry of the New Jersey Agricultural Experiment Station. The heifers were rated as excellent, very good, good plus, good, fair, or poor.

The coefficient of inbreeding as developed by Wright (1922) (1923) and utilized by Lush (1937) was employed in estimating the degree of inbreeding of the animals. In analyzing the growth records, "Students" *t*-test for unique samples, as given by Snedecor (1938), was used to determine whether the difference between certain means was significant. Inasmuch as normal size was one criterion used in selecting the foundation animals, it was of interest to determine whether the rate of growth made by heifers was normal. For this determination, Ragsdale's (1934) growth standards were employed. In order to obtain one figure that might represent the average type the following values were assigned to the various groups: excellent, 5; very good, 4; good plus, 3; good, 2; fair 1; and poor, 0. To determine if inbreeding inten-

sity influenced type score a population regression coefficient, with its standard error, was computed by the method of least squares (Snedecor, 1938).

Results

Comparison of Size at Birth and Growth Rate of Inbred and Outbred Heifers.

Size at birth. Birth weights and measurements are available on 76 inbred and 76 outbred heifers. The data are summarized in table 1. The mean body weight of the outbred heifers was 92 lbs. and that of the inbred heifers 96 lbs., the difference between the means not being significant. When the inbred heifers were grouped according to the degree of inbreeding, a considerable difference was found in the average body weights (87 lbs. to 101 lbs.). The only mean differences, however, that were found to be significant were the following ones: the 9-lb. difference in favor of calves with coefficients of inbreeding varying from 0.15–0.19 as compared with the outbred calves; the 10-lb. difference in favor of the inbred group 0.05–0.09 as compared with the inbred group 0.20 and over; and the 14-lb. difference in favor of the inbred group 0.15–0.19 as compared with inbred group 0.20 and over. With the exception of the inbred group 0.20 and over, all groups were above the Ragsdale standard.

All calf groups were above the Ragsdale standards for height at withers and, with the exception of the 0.20 and over group, for circumference of chest. The mean height at withers was significantly different in the following groups; inbred over outbred; 0.15–0.19 over outbred; and 0.05–0.09, 0.10–0.14, and 0.15–0.19 over 0.20 and above. The mean difference in circumference of chest was significant in the following groups: 0.05–0.09 over outbred and over inbred 0.20 and above, 0.15–0.19 over outbred; 0.10–0.14 and 0.15–0.19 over 0.20 and above.

Growth rate. At 5 months of age there were no significant differences in the 3 measurements between inbred and outbred animals. All groups were slightly above normal for body weight, height at withers, and circumference of chest. At 10 months of age outbred heifers weighed 21 lbs. more than did the inbred heifers; this difference is not significant. The inbred heifers, however, had not maintained the weight advantage that they had at birth. Even though the outbred heifers were 49 lbs. heavier than the 0.15–0.19 group, this difference was not significant. Of interest, though, is the fact that this latter group, which was heaviest at birth, was lightest at 10 months. The various groups were below normal for body weight and normal for height at withers and for circumference of chest. At 16 months of age the inbred and outbred heifers were similar in the 3 measurements. They were 13 per cent below the Ragsdale standard for body weight and 1 to 2 per cent below

the standard for height at withers and for circumference of chest. At 22 months of age inbred and outbred animals were similar in size; however, both groups were 14 per cent below normal for body weight and 0 to 3 per cent below normal for height at withers and for circumference of chest. The measurements of the animals after first and second calf were not compared with the Ragsdale standard because the measurements on our animals were taken at a definite stage of pregnancy and again at a definite stage of the lactation period. The inbred and the outbred animals were similar in size, yet all differences are in favor of the inbred heifers. The results are summarized in table 1.

Comparison of Inbred and Outbred Daughters of Herd Sires for Size at Birth and Growth Rate.

Of the 5 bulls listed in table 2, four are inbred and one (Career) is outbred. The inbred daughters of Chief weighed 11 lbs. more at birth than did his outbred daughters, and this difference is significant. The inbred daughters of Jewel Alice weighed 18 lbs. more at birth than did his outbred daughters, and in circumference of chest the inbred calves exceeded the outbred calves by 1.9 inches. These mean differences are highly significant. There were no significant differences between inbred and outbred calves sired by Career.

At 5 months of age the daughters of all sires were above normal for the 3 measurements. After 5 months of age, all groups tended to remain normal for height at withers and for circumference of chest, but for body weight they were subnormal. The degree of subnormality of body weight had a tendency to increase with age (table 2).

Influence of Inbreeding Intensity on Type Score.

One hundred and twelve heifers have been classified for body type. This group of heifers consisted of outbred animals and animals with varying coefficients of inbreeding. The average type rating of these heifers was 3.0 (Good plus) and the average coefficient of inbreeding was .08. The regression coefficient of type score on inbreeding intensity for this population of heifers is 1.16 (standard error 0.861). Therefore, with the number of animals observed, there is no evidence of a relation between the two variates, intensity of inbreeding and type.

Discussion

Additional data have been presented showing that inbreeding can be practiced successfully with dairy cattle, provided one begins with genetically superior animals and employs rigid selection. Inbreeding the Ormsby Sensation 45th family has produced progeny that were just as large at birth

TABLE 1.—COMPARISON OF SIZE AT BIRTH AND GROWTH RATE OF INBRED AND OUTBRED HEIFERS

Birth weight

Age	Number of Animals		Average weight or measurement					
	Outbred	Inbred	Outbred	Inbred	By per cent of inbreeding			
					.05–.09	.10–.14	.15–.19	.20 and over
			Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Birth	76	76	92	96	97	96	101	87
5 mos.	57	73	324	329	327	336	325	326
10 mos.	50	66	540	519	520	534	491	519
16 mos.	45	52	682	678	702	656	661	683
22 mos.	38	44	825	826	842	821	793	829
After first calf	12	20	1016	1027	1008	1029	1077	970
After 2nd calf	6	10	1159	1183	1242	1144	1166	1102

Height at withers

			Inches	Inches	Inches	Inches	Inches	Inches
Birth	76	76	30.4	30.7	30.8	30.8	31.2	29.6
5 mos.	57	73	39.4	40.0	39.8	40.2	40.2	39.8
10 mos.	50	66	45.0	45.4	45.4	45.7	45.0	45.4
16 mos.	45	52	47.7	48.2	48.1	48.5	47.7	48.5
22 mos.	38	44	49.6	50.8	50.9	50.9	50.0	52.0
After 1st calf	12	20	51.6	53.4	52.8	53.6	54.0	54.8
After 2nd calf	6	10	53.2	54.3	54.0	54.4	54.8	54.0

Circumference of chest

			Inches	Inches	Inches	Inches	Inches	Inches
Birth	76	76	31.2	31.5	31.9	31.2	31.9	30.4
5 mos.	57	73	46.5	47.0	47.0	46.8	47.2	47.0
10 mos.	50	66	56.8	56.4	56.8	56.8	55.6	55.6
16 mos.	45	52	62.3	62.2	62.3	62.6	61.5	61.9
22 mos.	38	44	66.6	67.0	67.4	66.6	66.3	67.4
After 1st calf	12	20	70.9	72.1	71.3	72.1	74.5	69.7
After 2nd calf	6	10	74.0	75.6	76.9	74.0	76.5	72.9

TABLE 2.—COMPARISON OF INBRED AND OUTBRED DAUGHTERS OF HERD SIRES FOR SIZE AT BIRTH AND GROWTH RATE

Growth Rate

Age of offspring	Sire	Number of animals		Mean body weight (lbs.)		Mean height at withers (in.)		Mean circumference of chest (in.)	
		Outbred	Inbred	Outbred	Inbred	Outbred	Inbred	Outbred	Inbred
Birth	Excelsior	1	13	95	97	29.1	30.7	30.3	31.9
	Chief	10	18	83	94	29.5	29.5	30.3	30.7
	Jewel Alice	15	4	96	114	30.7	31.1	31.5	33.4
	Conqueror	2	11	99	93	30.7	32.3	31.5	31.1
	Career	12	6	88	96	29.1	30.3	30.3	31.5
5 mos.	Excelsior	1	15	346	342	39.4	40.2	47.3	48.0
	Chief	8	18	319	319	39.8	40.2	46.9	46.9
	Jewel Alice	10	4	330	347	39.4	40.2	47.6	48.0
	Conqueror	2	13	348	321	41.0	39.8	48.5	46.5
	Career	10	6	315	316	38.6	39.0	46.5	46.9
10 mos.	Excelsior	1	12	498	524	43.2	45.7	58.4	56.7
	Chief	6	18	539	500	44.9	45.3	56.7	55.1
	Jewel Alice	10	4	532	516	44.9	44.1	57.5	55.5
	Conqueror	2	12	568	507	46.1	45.3	58.3	55.5
	Career	10	6	512	501	44.1	44.5	55.5	55.5
16 mos.	Excelsior	1	10	690	661	48.1	48.9	63.0	61.5
	Chief	6	15	646	646	47.3	48.1	61.5	60.6
	Jewel Alice	10	4	685	691	47.3	47.7	62.6	61.0
	Conqueror	1	4	720	642	50.0	47.7	62.2	61.0
	Career	10	6	658	675	47.3	47.3	61.0	62.2
22 mos.	Excelsior	1	7	910	824	50.8	50.8	68.2	67.8
	Chief	6	14	801	810	50.4	50.8	65.9	66.5
	Jewel Alice	9	4	832	822	50.4	50.0	66.5	67.0
	Conqueror	1	3	933	813	52.8	49.6	72.5	66.1
	Career	10	5	803	801	49.2	52.4	66.1	65.4

and grew just as rapidly as did the outbred progeny. It is true that after 10 months of age, inbred animals have been below the growth standard for body weight, but the same condition holds for the outbred animals. It would seem that either this is the result of management or that the 45th family is homozygous for dominant factors that regulate the rate of increase in body weight. That the 45th family carries factors for large size at birth is suggested by the fact that the inbred calves of 2 inbred sires of this family were significantly heavier at birth than were the outbred calves.

Conclusions

The inbreeding of a family of Holstein-Friesians produced animals that were as large at birth and grew as rapidly as did outbred animals of the same family. There appeared to be no relation between the intensity of inbreeding and type.

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CROSS-BREEDING FOR BEEF PRODUCTION[1]

RALPH W. PHILLIPS,[2] W. H. BLACK,[2] BRADFORD KNAPP, JR.,[2] and R. T. CLARK[3]
U. S. Department of Agriculture and Montana Agricultural Experiment Station

CROSS-BREEDING has been used extensively in certain classes of livestock, either as a means of increasing production or to produce a type of animal that more nearly meets market demands than do the parent strains usually raised. It has been estimated that 60 to 70 per cent of the swine marketed in this country are crossbreds and that over 10 per cent of the range sheep of the West are crossbreds (U.S.D.A., 1940). Crossbreeding has not been practiced with beef cattle to the extent that it has in other meat animals, but results that are available indicate that there may be possibilities of increasing production by this practice.

Several reports are found in the literature dealing with the results of beef and dairy cattle crosses (Parlour, 1913) (Gowen, 1918) (Fuller and Roche, 1929) and various tests have been made to determine the possibilities of generic crosses, such as the crosses of Brahman cattle with Herefords and Shorthorns described by Black, Semple, and Lush (1934) and crosses of Zebu and dairy, dual-purpose, and beef breeds in Jamaica and Trinidad described by Hammond (1932).

Wentworth (1912) summarizes data from the Smithfield Show (England) on Hereford, Shorthorn, Angus, and "blue-gray" cattle. The "blue-gray" cattle, produced by mating white or light roan Shorthorns to black Galloway or Angus cattle, had the highest daily gain by a slight margin. Wentworth also refers briefly to an experiment with "blue-gray" cattle which was started at the Iowa Experiment Station in 1902. He concludes that the "blue-gray" cattle have demonstrated their equality or even superiority as market animals.

Hammond (1920) studied carcasses of steers and heifers exhibited at the Smithfield show. These included cattle of several pure breeds and a wide variety of crosses. He found that crossbreds have a slightly larger proportion of carcass, and larger proportions of suet fat (steers only), gut fat, tongue, heart and "unaccounted for" than pure breeds, but that pure breeds have a larger portion of suet fat (heifers only), head, hide, and blood. Proportions of tripe and intestine were about the same in each group.

[1] Based on work conducted cooperatively by the U. S. Department of Agriculture and the Montana Agricultural Experiment Station.

[2] Bureau of Animal Industry, Beltsville, Md.

[3] Montana Agricultural Experiment Station, Bozeman, Montana.

Shaw and MacEwan (1938) report on crosses of Shorthorn × Aberdeen-Angus, Hereford × Shorthorn, Aberdeen-Angus × Hereford, Hereford × Galloway, Shorthorn × Galloway, and Aberdeen-Angus × Galloway. In each cross, cows of both breeds were crossed with bulls of the opposite breed in the cross. Purebred animals of all four breeds were used as controls. The findings indicated that the crossbred animals had a definite advantage over those of pure breeding in rate of gain and in quality of carcass. Of the various crossbred groups, those of Shorthorn × Aberdeen-Angus and of Aberdeen-Angus × Shorthorn breeding gave the highest percentage of top grade carcasses.

Daugherty (1939) gives a preliminary report on work at the North Dakota Experiment Station which indicates that crossbred calves, produced by crossing Aberdeen-Angus and Shorthorn cattle, may make somewhat faster gains than purebreds.

Material and Methods

The results reported in this paper are from the first phase of an experiment designed to test further the possibilities of cross-breeding in beef cattle. The experiment was so planned that it would test the possibilities of maintaining heterosis through continual crossing. The first cross was made with purebred Shorthorn bulls on Hereford cows. These F_1 cows will be mated to Angus bulls and their triple-cross female offspring to Hereford bulls. From that point the order of the bulls used on each successive generation will be Shorthorn, Angus, and Hereford. This work is being conducted at the U. S. Range Livestock Experiment Station, Miles City, Montana. The breeding program with Hereford cattle at this station is designed to develop superior strains of purebred Herefords and selection of bulls are based upon the results of progeny tests. Data from these experiments also serve as the basis for comparison of crossbred and purebred offspring.

Both purebred and crossbred calves used in the present study were born in the same six-week period. About the middle of October each year all calves were weaned on the same day and put on record of performance tests. The steers were individually fed in stalls and daily records were kept on grain and hay consumption for each animal. In 1939–40 the grain ration consisted of 50 per cent No. 2 yellow corn and 50 per cent dried molasses beet pulp. Alfalfa hay was fed at the rate of 3 to 5 pounds per head per day and was maintained at the same rate for all steers for each 28-day period. The grain ration for 1940–41 consisted of 6 parts of No. 2 yellow corn, 3 parts of dried molasses beet pulp, 1 part of wheat bran, and 1 part of linseed meal. Alfalfa hay was fed ad libitum. The steers were fed until an average weight of approximatly 900 pounds was reached. In 1939–40 the feeding period was 281 days and in 1940–41 it was 265 days.

The bulls used were registered purebreds. In 1939–40 four purebred Hereford sires and two purebred Shorthorn sires were used, whereas in 1940–41 five Herefords and two Shorthorns were used. Part of the cows used were registered and part were unregistered. The unregistered animals were, for the most part, descendants of a group of unregistered purebred and high-grade Hereford cows that was purchased in 1924. Since that time only registered bulls have been used on these females and the animals used in this work were from 2 to 5 generations removed from the original stock. They were not distinguishable from the registered animals. Some of the unregistered animals were descendants of registered stock. For this study, the registered and unregistered animals were considered equal, but if the steers from registered parents had any advantage it was in favor of the purebred group since 46.2 per cent of these were from registered dams while only 10.5 per cent of the crossbreds were out of registered cows.

Data and Discussion

Production and Marketing Data

The data for each of the two years are summarized in table 1. The significance of the differences between purebreds and crossbreds in the more important characteristics is indicated in table 2.

In both years the crossbred steers were heavier at birth than the purebreds. This advantage increased at weaning so that in 1939–40 there was a difference of 27 pounds and in 1940–41, a difference of 14 pounds. At the end of the feeding period the crossbred steers had surpassed the purebreds by approximately 52 and 85 pounds and these differences are statistically significant (table 2).

The daily gain in the feed-lot was materially smaller for 1939–40 than for 1940–41, although in both years the crossbred steers outgained the purebred steers. The smaller gain of 1939–40 was due to the limited feeding schedule. Since the steers were requied to consume a constant quantity of hay each day, the concentrates were limited to what the steers would consume above the hay ration. Under this limited feeding program, neither group of steers had an opportunity to express their full growth potentialities, but the crossbred steers gained significantly more rapidly than the purebred steers. In 1940–41 both groups had opportunity to develop to the maximum of their inherited ability and the average of the crossbred steers was over a quarter of a pound more per day gain than the purebreds. This difference is highly significant.

In both years the crossbreds ate more feed than the purebreds but in final efficiency of gain the crosbred steers were somewhat more efficient than the

TABLE 1.—SUMMARY OF DATA ON PUREBRED AND CROSSBRED STEERS

Items compared	1939–1940		1940–1941	
	Purebred	Crossbred	Purebred	Crossbred
Number of steers	29	23	38	34
Birth weight	79.5	83.2	79.1	84.8
Age at weaning	181.8	184.5	180.3	174.7
Weaning weight	402.6	429.1	402.6	416.8
Final feed lot weight	875.4	927.6	883.5	968.3
Feed lot gain	472.8	498.5	480.9	551.5
Daily gain in feed lot	1.68	1.77	1.81	2.08
Feed consumed per steer:				
Grain mixture	2763.1	2910.5	2691.2	3015.4
Alfalfa hay	1016.4	1039.9	1051.1	1251.5
Total digestible nutrients consumed	2674.3	2800.4	2628.2	2982.4
Gain per 100 lbs. T.D.N. consumed (efficiency)	17.68	17.80	18.30	18.49
Sales weight	853.8	902.8	850.8	927.6
Cold carcass weight	500.2	536.8	497.6	558.8
Dressing per cent	57.1	57.9	56.3	57.7
Slaughter steer grade	16.8	16.7	16.0	15.6
Carcass grade	16.6	14.4	15.9	15.5
Cost of feed per 100 pounds gain	7.16	7.12	8.28	8.18
Sales price per hundred weight	10.50	10.34	11.58	11.64
Sales value per steer	89.37	93.33	98.57	107.92
Total cost of feed and marketing	40.20	42.44	47.12	53.08
Returns per steer	49.17	50.89	51.45	54.84

TABLE 2.—SUMMARY OF SIGNIFICANCE OF DIFFERENCES BETWEEN PUREBREDS AND CROSSBREDS IN CERTAIN IMPORTANT CHARACTERISTICS

Item	1939–40	1940–41
Final feed-lot weight	**	**
Feed lot gain	**	**
Efficiency of gain	—	—
Slaughter grade	—	—
Carcass grade	—	—
Dressing per cent	*	**

*—$P \leqq .05$.
**—$P \leqq .01$.
— = not significant.

purebreds. The differences in efficiency were not statistically significant, however.

The crossbred steers dressed higher in both years than the purebreds. In 1939–40 the difference in dressing per cent was only 0.73 per cent but was

statistically significant ($P \leqq .05$). In 1940–41 the difference in dressing per cent was 1.39 per cent in favor of the crossbred steers and this difference is highly significant ($P \leqq .01$). In slaughter steer grades and carcass grades the crossbred steers were graded slightly superior to the purebreds in both years, but the differences are not significant. The sales price per hundredweight indicates that the packer buyers thought equally well of both groups since the sales price is approximately the same.

In both years the cost of feed and marketing was higher for the crossbreds than for the purebreds, due to the larger consumption of feed. However,

TABLE 3. PERCENTAGE OF STEER DAYS IN WHICH DIGESTIVE DISORDERS OCCURRED

Items compared	1939–40			1940–41		
	Purebred	Crossbred	Difference	Purebred	Crossbred	Difference
Total steer days	8,149	6,463	—	10,070	9,010	—
Per cent of steer days with steers bloating	0.82	0.09	0.73**	2.99	1.31	1.68**
Per cent of steer days with steers off feed	0.34	0.74	0.40**	0.07	0.04	0.03
Per cent of steer days with steers scouring	0.15	0.11	0.04	1.10	1.05	0.05
Per cent of steer days with digestive disorders	1.31	0.94	0.37*	4.16	2.41	1.75**

*—$P \leqq .05$.
**—$P \leqq .01$.

the crossbred steers returned a greater profit above feed and marketing costs than did the purebreds. This difference was $3.39 per head in 1940–41 where each group had ample opportunity to develop.

Digestive disorders

Much of the loss sustained in the feeding of beef cattle arises from digestive disorders. In this study digestive disorders were classified into three general groups: (1) bloat, (2) off-feed, in which the steer refused feed and was listless, and (3) scouring. The results of a tabulation of these disorders are shown in table 3.

The per cent of steer days with digestive disorders was materially lower in 1939–40 than in 1940–41 but this is due to two conditions—limited feeding in 1939–40 and the occurrence of coccidiosis in 1940–41. Within years the purebreds experienced 1.4 and 1.7 times as many digestive disorders as

the crossbreds. Bloating was more frequent in the purebreds than in the crossbreds in both years. In 1940–41 the bloating in the crossbreds was confined to one steer that became a chronic bloater, whereas in the purebreds five steers were chronic bloaters. The per cent of steer days off-feed is low in both years and the difference was in favor of the purebreds in 1939–40. These figures include only those days where off-feed was not due to bloat or scouring. The per cent of steer days with steers scouring is about equal for the purebreds and crossbreds. The indications are that the crossbreds were somewhat less subjective to digestive disorders than the purebreds. This subject should receive more study.

Variability

An analysis was made to determine whether the crossbreds in this study were more or less variable than the purebreds. The coefficients of variation for purebred and crossbred steers for each year are shown in table 4. The number of bulls used in the purebred group exceeded the number used to sire the crossbred steers, and this might have increased the relative variability in the purebred group. Therefore, differences due to sires were determined and the coefficients of variation given are based on the standard deviations corrected for these differences.

In general, the variation was less in 1939–40 than in 1940–41, due to the influence of limited feeding. The purebred steers were more variable than were the crossbreds in all the factors studied in 1940–41, and in three of the six in 1939–40. The factors studied were not all independent of each other, of course. In final feed-lot weight and efficiency of gain the crossbred steers were materially less variable than the purebreds.

Discussion

The results reported above have a bearing on the problem of efficient beef

TABLE 4. COMPARISON OF THE VARIABILITY OF PUREBREDS AND CROSSBREDS, EXPRESSED IN COEFFICIENTS OF VARIATION

Items compared	1939–1940		1940–1941	
	Purebreds	Crossbreds	Purebreds	Crossbreds
Final feed-lot weight	6.50	4.12	8.66	6.31
Feed lot gain	7.61	6.49	12.73	7.46
Efficiency of gain	7.76	3.49	8.31	5.24
Slaughter grade	14.98	20.08	17.62	15.34
Carcass grade	18.47	18.79	17.80	15.85
Dressing per cent	1.69	2.42	2.56	2.29

production in this country, and indicate one means by which production per animal unit can be increased.

The results indicate that the range cattle producer who is in a position to grow crossbreds for sale to feed-lot operators should expect a greater return per cow unit because of the somewhat higher weaning weight and the greater desirability of the crossbreds in the feed-lot. The cattle feeder or Corn Belt farmer should expect greater returns from feeding operations with crossbreds because of larger and more uniform gains and the tendency of crossbreds to have fewer digestive disorders.

Crossbreeding cannot be recommended as a permanent means of improvement. It is based on the crossing of established breeds which differ in genetic constitution, and the chief beneficial effect is in the first generation. Work with swine (Winters, Kiser, Jordan and Peters, 1935) has indicated that heterosis may be maintained with a system of criss-crossing, thus making it possible to use crossbred females for breeding, but always going back to the pure breeds for sires. Later results in the project from which the present data were taken should shed some light upon the effectiveness of this practice in beef cattle.

Summary and Conclusions

Data are presented on the first phase of an experiment designed to test the possibilities of maintaining heterosis in beef cattle with a system of criss-crossing, using Hereford cows as a foundation, and using Shorthorn, Angus, and Hereford bulls to sire successive generations of offspring. The present study is based on 57 crossbred steers from Hereford cows and sired by Shorthorn bulls. Sixty-seven Hereford steers served as controls. Analyses of these data show that:

1. The crossbred calves gained more rapidly in the feed-lot than the purebreds and were heavier at time of marketing. These differences were highly significant.

2. The differences found between the purebreds and crossbreds in efficiency of gain, slaughter grade, and carcass grade were not statistically significant.

3. The dressing percentage was higher in the crossbred than in the purebred steers.

4. The crossbreds had fewer digestive disorders in the feed-lot than the purebreds.

5. In general, the crossbred steers were less variable than the purebred steers.

These findings indicate that crossbreeding offers a means of increasing production per animal unit, and that it should be profitable, under conditions

where the practice is compatible with other breeding and management practices.

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THE IMPORTANCE OF BODY WEIGHT IN SELECTION OF RANGE EWES

CLAIR E. TERRILL AND JOHN A. STOEHR
United States Department of Agriculture[1]

IN the selection of range ewes it is essential that the characters of greatest economic importance be given the major emphasis. Lamb and wool production are the chief sources of income from range sheep with a greater proportion of the income generally resulting from lamb production.

It is difficult to practice effective selection for high lamb production because this cannot be adequately evaluated until rather late in a ewe's life and also since it is materially affected by environment. It is therefore highly desirable to select sheep on factors that are associated with lamb production which may be measured rather early in life. It is the purpose of this study to determine the relationship of yearling body weight to lamb and wool production.

Body weights taken in the winter have been found to be associated with amount of production of both lamb and wool in the following spring and summer. Size of the ewe was reported by Joseph (1931) to be the most accurate single measure of the ability of ewes of the fine-wool type to produce heavy lamb crops. In addition heavier fleeces were produced by the larger ewes. Hunt (1935) working with both mutton and fine-wool sheep also found that lamb and wool production increased with the size of the ewe. However, production, per 100 pounds of ewe, decreased as the size of the ewe increased. Bonsma (1939) reported that within breeds milk production of ewes increased with body weight. Spencer *et al* (1928) found a fairly positive relation between body weights taken after shearing at one year of age and unscoured fleece weights.

Material and Methods

Lifetime records of body weights, lamb, and wool production from 758 range ewes over a 15-year period were used in this study. A total of 214 Columbia, 241 Corriedale, and 303 Rambouillet ewes born during the years from 1925 to 1933 that remained in the flock of the U. S. Sheep Experiment Station for 5 years or longer were included.

All breeds were handled in one band under typical intermountain range conditions. They were required to graze on the range from the opening of spring in April until almost snowbound in December or January. Alfalfa

[1] U. S. Sheep Experiment Station and Western Sheep Breeding Laboratory, Dubois, Idaho

TABLE 1.—LAMB PRODUCTION WITHIN GROUPS OF RANGE EWES DIVIDED ON THE BASIS OF FALL YEARLING BODY WEIGHT

Breed	Grouping of ewes on basis of fall yearling weight	No. of ewes	Average fall yearling body weight	Average 2–5 year body weight	Lamb production during					
					First four lambing years			Lifetime		
					No. lambs weaned per 100 ewe years	Average weaning weight*	Weight of lambs weaned per ewe year*	No. lambs weaned per 100 ewe years	Average weaning weight*	Weight of lambs weaned per ewe year*
			Lbs.	*Lbs.*		*Lbs.*	*Lbs.*		*Lbs.*	*Lbs.*
Columbia	114 lbs. & lower	49	109	130	82	73	60	85	74	63
	115–130 lbs.	116	122	136	97	77	74	99	77	77
	131 lbs. & higher	49	139	149	91	82	75	95	82	78
Corriedale	100 lbs. & lower	55	96	108	90	67	61	92	68	63
	101–115 lbs.	129	108	116	93	71	66	97	71	69
	116 lbs. & higher	57	123	127	104	72	75	107	72	76
Rambouillet	105 lbs. & lower	80	101	119	75	69	52	79	69	55
	106–118 lbs.	147	112	125	82	71	58	85	71	60
	119 lbs. & higher	76	123	135	93	72	67	97	72	69

* Weaning weights were taken at an average age of about 130 days.

hay was fed during the intervening winter months. Concentrates such as cottonseed cake or oats were fed just before and during lambing which usually took place during April. The spring and fall grazing was on a sagebrush-grass type range. Summer grazing was on the Targhee National Forest at altitudes from 6,000 to 8,500 feet. Winter grazing was on the Salmon National Forest where they remained until storms forced them down into the winter feed lots in December or January.

Determination of lamb production was based on the pounds of lamb weaned per ewe year. This was obtained by dividing the total weight of lambs weaned at about 130 days by the number of lambing years the mother was in the flock.

Body weights of ewes were taken twice each year, just after shearing around June 1 and at culling time about the middle of October. Lifetime averages for body weight include the 8 weights taken in June and October from the 2nd to 5th years of age, inclusive.

Unscoured fleece weights were taken each year as the sheep were shorn. Length of staple was measured just prior to shearing each year. It was measured to the nearest one-eighth inch near the mid-portion of the side of each ewe by each member of a committee of three and the average of these was used as the length. The lifetime averages include the 4 fleece weights or fleece lengths taken from the 2nd to 5th years of age, inclusive.

Results

The records of ewes of each breed were divided into 3 groups on the basis of the fall yearling weights. These weights were taken at culling, which was usually about the middle of October. The limits of the 3 groups within each breed were selected so that approximately one-fourth of the ewes were included in the lightest group, one-fourth in the heaviest group and the other one-half in the middle group. Average body weights and lamb production for these groups are presented in table 1.

In this study most of the comparisons were based on the first 4 years' lamb production as all ewes included had equal opportunity during those years. In the succeeding years many ewes dropped out each year. The lifetime lamb production for each group of ewes has been included in table 1. This production is more representative of the flocks included as all ages are present. It is noted that lamb production per ewe year was greater after the fourth lambing year than before.

Within breeds, ewes which were heavier as yearlings, on the average weaned more pounds of lamb per ewe year during their lifetimes. Differences between the means for pounds of lamb weaned per ewe year during the first 4 years were all significant with the exception of the middle and heavy

groups of Columbias. This advantage in favor of the heavier ewes was due both to a higher percentage of lambs weaned and to heavier weaning weights. In general the per cent of lambs weaned accounted for a much greater proportion of the differences in lamb production among body weight groups than did weaning weight. Thus it appears that within breeds the advantage in lamb production of the heavier ewes was due more to higher reproductive ability than to factors which contributed more to weaning weight such as milk supply and growth rate. The correlation coef-

TABLE 2.—FACTORS CONTRIBUTING TO LAMB PRODUCTION WITHIN GROUPS OF RANGE EWES DIVIDED ON THE BASIS OF FALL YEARLING BODY WEIGHT

Breed	Grouping of ewes on basis of fall yearling weight	No. ewe years*	No. ewes lambing per 100 ewe years	No. lambs born per 100 ewes lambing	No. live lambs per 100 lambs born	No. lambs weaned per 100 live lambs born
Columbia	114 lbs. & lower	196	90	120	93	82
	115–130 lbs.	464	96	120	93	90
	131 lbs. & higher	196	93	127	89	86
Corriedale	100 lbs. & lower	220	95	110	93	93
	101–115 lbs.	516	96	114	92	92
	116 lbs. & higher	228	97	119	97	93
Rambouillet	105 lbs. & lower	320	90	112	91	82
	106–118 lbs.	588	93	117	92	81
	119 lbs & higher	304	96	126	95	81

* First 4 lambing years of each ewe.

ficients between fall yearling body weight and average pounds of lamb weaned per ewe year during the first 4 lambing years were 0.25, 0.31 and 0.29, for the Columbias, Corriedales, and Rambouillets, respectively, and they were all highly significant. The average increase in pounds of lamb weaned per ewe year with each pound increase of fall yearling weight of the mothers was 0.49, 0.48, and 0.63 for the Columbias, Corriedales, and Rambouillets, respectively.

Factors which show more specific differences in reproductive ability among the body weight groups are presented in table 2. In general, the heavier groups have definite advantages over the lighter groups in the number of ewes lambing per 100 ewe years and in the number of lambs born per 100 ewes lambing. With the exception of the Columbias the heavier groups also produced a higher proportion of live lambs. There was no definite trend among the groups in the proportion of lambs weaned of live lambs born. Thus, the heavier groups which had more lambs also had the additional

milking and mothering ability necessary to carry the larger number of lambs to weaning. The number of lambs born, or twinning ability, appeared to be more than twice as important as the number of ewes lambing per ewe year while loss of lambs at birth and from birth to weaning were least important in bringing about differences between the light and heavy groups of ewes in per cent of lambs weaned.

The correlation of fall yearling weight and lamb production within groups of ewes born as singles and as twins was significant in every case and the correlation coefficients were of about the same magnitude as for the combined groups of single and twin ewes. The difference in lamb production between ewes born as singles or as twins was not great. Columbia and Rambouillet ewes born as singles produced slightly more pounds of lamb per ewe year than did ewes born as twins of these breeds while Corriedale twin ewes produced slightly more pounds of lamb per ewe year than did the single ewes. The single ewes were slightly heavier than the twin ewes both as yearling and mature ewes in each of the 3 breeds. The differences ranged from 1.5 to 2.5 pounds. The failure of the lamb production of the Corriedale twin ewes to be strictly in harmony with their body weights may be attributed to the small number of twin ewes involved as only 17 per cent of the Corriedale ewes had been born as twins while 37 per cent of the Columbias and 24 per cent of the Rambouillets were twins.

While heavier ewes have higher lamb production within breeds this does not necessarily hold between breeds. Thus, the Corriedales with lighter body weights produced more pounds of lamb per ewe year than did the slightly heavier Rambouillets. The advantage of the Corriedales was due entirely to a higher per cent of lambs weaned rather than to weaning weights which were slightly heavier in the case of the Rambouillets. The Columbia was the largest breed studied and it had the highest lamb production. It is noted that there is little difference in lamb production between the middle and heavy groups of Columbia ewes. The lamb production of the middle Columbia group is somewhat higher than the light weight group in comparison with the differences in the other 2 breeds. However, the middle group of Columbias is very similar in body weight and lamb production to the heavy group of Corriedales. It seems reasonable that the failure of the heavy group of Columbia ewes to exceed definitely the middle group in lamb production might be attributed to range feed conditions which were inadequate to produce maximum production with sheep of that size. This may indicate that for optimum lamb production there should be a balance between body size and available range feed. Thus heavier breeds of sheep would be adapted to range country with abundant feed and the lighter breeds to areas with more sparse vegetation.

It is to be expected that larger sheep will require greater amounts of feed and while the heavier ewe produces more pounds of lamb than the lighter ewe this is not necessarily more efficient production. However, it is believed that with range sheep the cost of operation is more related to the number of sheep than to the feed requirements of individual sheep and if this is true the larger sheep would, in general, be more profitable provided there was sufficient range feed available. Information is needed on the relation of the size of the sheep to the carrying capacity of the range.

Lamb production per unit of body weight was greater for the heavier ewes. Pounds of lamb weaned per 100 pounds of ewe per year, determined from the first four lambing years and the average 2–5 year body weight were 46, 54, and 50 pounds, respectively, for the light, middle, and heavy groups for the Columbia; 56, 57, and 59 pounds for the Corriedale, and 44, 46, and 50 pounds for the Rambouillet. Thus, with the exception of the heavy group of Columbias the larger ewes, within a breed, also produce slightly more pounds of lamb per unit of body weight. Efficiency of lamb production in the heavy group of Columbias may have been interfered with because their feed requirements exceeded the available supply.

Although there were definite breed differences in the level of lamb production there was little variation in the difference between the lightest group and the heaviest group among breeds. These differences ranged from 13 to 15 pounds of lamb weaned per ewe year. In other words, selection on yearling body weight would have about the same effectiveness for increased lamb production in each of the breeds studied.

It is common observation that high lamb production tends to reduce body weight and low lamb production tends to increase body weight. This fact is clearly demonstrated in this study by an inverse relationship between average lifetime body weight and pounds of lamb weaned per ewe year when considered independently of the fall yearling weight. Thus, ewes heavier as yearlings have their mature weights decreased because of their higher lamb production while the lighter yearling ewes have their mature weights increased because of their lower lamb production. The effect of lamb production on body weight is probably due to decrease or increase in condition or degree of fatness rather than to changes in growth. This effect of lamb production on mature body weight emphasizes the desirability of basing selection on body weights taken prior to the first breeding.

There was a slight advantage in the average 2–5 year fleece weight in favor of the ewes which had been heavier as yearlings as shown in table 3. The difference between the lighest group and heaviest group was 0.7, 0.4, and 0.2 pound of wool per ewe year for the Columbia, Corriedale, and Rambouillet, respectively. There was practically no differences among the groups in average 2–5 year fleece lengths.

The tendency for the fleece weights to be relatively the same in the three body weight groups was due in part to the greater lamb production of the heavier ewes. This is shown by an inverse, although low relationship between average lifetime fleece weight and pounds of lamb weaned per ewe year. When the mean fleece weights of the various groups were adjusted to a common lamb production by analysis of covariance the differences between the light and heavy groups of ewes were increased to 0.8, 0.5, and 0 5 pounds for the Columbia, Corriedale, and Rambouillet, respectively.

The lighter ewe produced slightly more wool per unit of body weight as shown by the weight of fleece per 100 pounds of ewe per year which was 8.9, 8.8, and 8,4 pounds, respectively, for the light, middle, and heavy groups for the Columbia; 9.3, 8.9, and 8.2 pounds for the Corriedale, and 9.8, 9.5, and 8.8 pounds for the Rambouillet.

TABLE 3.—FLEECE PRODUCTION WITHIN GROUPS OF RANGE EWES DIVIDED ON THE BASIS OF FALL YEARLING BODY WEIGHT

Breed	Grouping of ewes on basis of fall yearling weight	No. of ewes	Average 2–5 year fleece weight	Average 2–5 year fleece length
			Lbs.	*Inches*
Columbia	114 lbs. and lower	49	11.8	3.5
	115 to 130 lbs.	116	12.0	3.4
	131 lbs. and higher	49	12.5	3.5
Corriedale	100 lbs. and lower	55	10.0	3.5
	101 to 115 lbs.	129	10.3	3.6
	116 lbs. and higher	57	10.4	3.6
Rambouillet	105 lbs. and lower	80	11.7	2.5
	106 to 118 lbs.	147	12.0	2.5
	119 lbs. and higher	76	11.9	2.5

Summary

Ewes which were heavier in the fall as yearlings, on the average, weaned more pounds of lamb per ewe year during their lifetime. This advantage of the heavier ewes was due more to a higher per cent of lambs weaned than to heavier weaning weights.

Variation in lamb production associated with yearling body weight existed within groups of ewes born as singles and as twins. There was no consistent difference in lamb production between ewes born as singles and twins.

Selection on yearling body weight would have about the same effectiveness for increased lamb production within each of the breeds studied as the

differences in lamb production between the lightest and heaviest groups of ewes was practically the same for each of the 3 breeds. These differences varied from 13 to 15 pounds of lamb weaned per ewe year.

There was an inverse relationship between average lifetime body weight and pounds of lamb weaned per ewe year when considered independently of fall yearling weight. This emphasizes the desirability of basing selection on body weight taken prior to the first breeding.

There was a slight advantage in lifetime average fleece weight in favor of the ewes which had been heavier as yearlings but there was practically no differences in the lifetime fleece lengths associated with yearling body weight.

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RELATIONSHIP BETWEEN WEANLING AND YEARLING FLEECE CHARACTERS IN RANGE SHEEP

ELROY M. POHLE[1]
U. S. Department of Agriculture[2]

SYSTEMATIC selection and culling of sheep has been practiced by breeders for some time as a means of increasing the quality and quantity of wool produced. A careful analysis of the fleece is usually first made when the sheep is in full yearling fleece. However, in a breeding program in which rams are progeny tested, often many of the animals have been disposed of before they reach the yearling age. This analysis has been made to determine if it is desirable to make evaluation of the fleece at weaning age, at which time a larger percentage of the progeny may be included in the study.

Lambert, Hardy and Schott (1938) state that "certain weanling characteristics may be used satisfactorily in predicting the yearling fleece characteristics" but suggest that "further studies are needed before these relations can be applied in a breeding program." Since the above preliminary report was made, more data have been accumulated and so it is the purpose in this paper to discuss further the relationship of fleece characters studied in the same sheep as weanlings and yearlings and also to test the reliability of making this study on only one sample.

Material and Methods

A total of 170 weanling ewes was selected for this purpose from the flocks at the U. S. Sheep Experiment Station and Western Sheep Breeding Laboratory, Dubois, Idaho. Wool samples were taken from the weanling Rambouillet ewe lambs the first week in October, 1938 and from the same sheep remaining in the flock as yearlings the latter part of May, 1939. The Corriedale and Columbia weanling ewe lambs were sampled the first part of November and were again sampled as yearlings the latter part of May, 1939. The Rambouillet sheep were born during May, 1938, while the Corriedale and Columbia sheep were born during April, 1938.

Sampling Procedure

Two adjacent wool samples as illustrated in figure 1 were taken with electric clippers (as close to the skin as possible) from the left side of each weanling lamb. These were later scoured and used for both percentage clean yield and density index determinations. The length and width of each area

[1] Acknowledgement is made to Dr. Clair E. Terrill of this Laboratory for his assistance in the study.
[2] U. S. Sheep Experiment Station and Western Sheep Breeding Laboratory, Dubois, Idaho.

and the staple length were measured. The length of staple was measured to the nearest 0.2 centimeter at the ends of each clipped area and the mean of the two measurements was used. The size of each sampling area was approximately 1 centimeters by 5 centimeters, designated as left front and left rear for the weanlings. The approximate weight of the wool samples from weanlings was 8 to 15 grams and on yearlings 20 to 30 grams. The left front sampling area was just back of the upper part of the scapula and the left rear anterior to and slightly below the point of the ileum. A small tuft

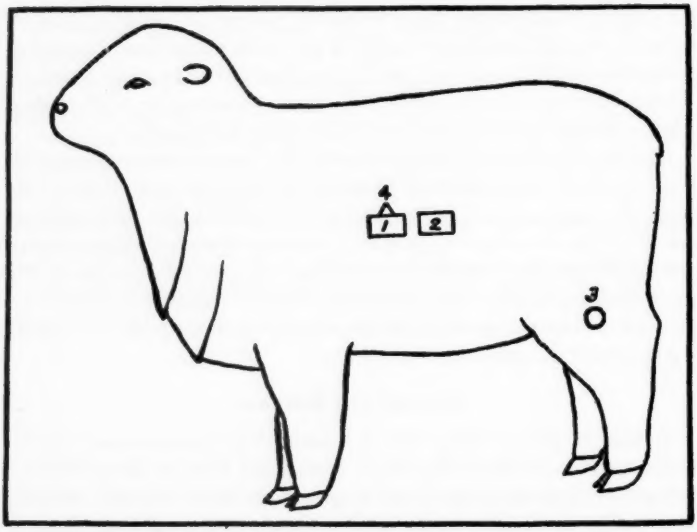

Figure 1. Showing sampling locations. The left side was sampled on weanlings and the right side on yearlings, at comparable locations. (1) Front sampling location. (2) Rear sampling location. (3) Thigh sample for fineness. (4) Side sample for fineness.

of wool was taken immediately above the front cleared area as illustrated in figure 1. Another sample for fineness determination was taken on the thigh even with the underline as illustrated in "3," figure 1 (Hardy, 1935). Similar samples were taken on the right side as yearlings in comparable locations. Density and clean yield percentages were calculated according to the method described by Hardy (1934).

Results

In length of fleece there is a significant relationship between weanling and yearling wool as indicated by the regression and correlation coefficients

in table 1. The prediction of yearling length from weanling length was found to be most reliable in the Rambouillet and Corriedale breeds where from 20 to 28 per cent of the variation in the yearling fleece length was explained by variation in the weanling fleece length, whereas the corresponding percentages for the Columbias were 14 to 17. It will be observed from the data in table 1 that all measurements for length of fleece are in very close agreement for the front and rear areas when taken either at weanling or yearling ages.

The Rambouillet weanlings at 5 months of age had attained about 40 per cent of their yearling fleece length while the Corriedales and Columbias, at 7 months of age, had attained 65 and 57 per cent respectively of their yearling fleece lengths.

There was a close relationship for fleece length in most cases between two adjacent samples as shown in table 2. The slightly lower relationship indicated in this table between the Columbia samples may partially explain the lower predictive value of Columbia weanling fleece length.

There was a definite relationship between the clean yield of wool obtained from weanling samples and that obtained from yearling samples as shown by the highly significant regression and correlation coefficients presented in table 1. Clean yield in the weanling samples was most reliable in the Columbia as shown by the per cent reduction from the standard deviation to the standard error of estimate in table 1. This difference may probably be attributed to greater variability in clean yield among the individual Rambouillets as compared with the individual Corriedales and Columbias.

The clean yield of the yearling samples was definitely lower than that of the weanling samples in each of the three breeds studied. This indicates that a greater proportion of the grease, dirt and foreign material that goes to make up shrinkage in the yearling fleece is added after weaning.

The reliability of predicting the clean yield of one wool sample from another adjacent sample taken at the same time is about twice as great as the reliability of predicting yearling clean yield from weanling clean yield, and the difference is much less than that in the case of the Rambouillet as shown by the per cent reduction from standard deviation to the standard error of estimate in tables 1 and 2.

The relationship of density index determinations between weanlings and yearlings was barely significant and not significant in the Corriedale as shown by the regression and correlation coefficients in table 1. Thus it appears that very little dependence can be placed on density determinations of the weanling samples when predicting density in the same fleeces as yearlings. There are but slight differences between the mean densities for weanlings and yearlings.

TABLE 1.—RELATIONSHIPS BETWEEN WEANLING AND YEARLING FLEECE CHARACTERS

Breed	Number of animals	Characters	Position of sample	Mean		r	Regression of weanling on yearling[3]		Per cent reduction from standard deviation of mean to standard error of estimate
				Weanling	Yearling		a	$b_{y.x}$ with standard error	
Rambouillet	74	Length (cm.)	Front	2.4±.06[2]	5.7±.09[2]	0.65	3.42	0.96±.013	24
			Rear	2.2±.06	5.7±.09	0.71	3.30	1.07±.013	28
		Clean (%)	Front	37.6±.95	32.6±.57	0.80	15.44	0.45±.004	40
			Rear	37.0±.98	34.7±.47	0.71	21.95	0.34±.040	29
		Density[1]	Front	2.2±.04	2.6±.04	0.27	2.00	0.26±.011	3
			Rear	2.3±.05	2.7±.05	0.30	2.06	0.26±.011	4
		Fineness (microns)	Side	20.7±.15	19.0±.17	0.46	8.62	0.52±.012	11
			Thigh	22.1±.17	21.5±.22	0.18	16.28	0.24±.015	1
Corriedale	50	Length (cm.)	Front	6.1±.13	9.3±.17	0.68	3.92	0.89±.014	25
			Rear	6.1±.11	9.5±.16	0.60	4.41	0.84±.016	20
		Clean (%)	Front	57.0±.69	40.0±.75	0.74	−2.23	0.74±.012	26
			Rear	55.4±.79	42.9±.80	0.69	4.49	0.69±.011	26
		Density[1]	Front	2.4±.05	2.3±.05	0.23	1.86	0.19±.012	2
			Rear	2.3±.06	2.4±.05	0.23	1.64	0.33±.012	2
		Fineness	Side	21.6±.32	21.2±.25	0.39	14.47	0.31±.011	7
			Thigh	24.4±.43	24.4±.42	0.48	12.96	0.47±.012	11
Columbia	51	Length (cm.)	Front	5.1±.10	8.9±.16	0.54	4.54	0.85±.019	14
			Rear	5.2±.11	9.2±.17	0.57	4.56	0.89±.019	17
		Clean (%)	Front	55.9±.51	41.0±.70	0.47	4.92	0.65±.017	15
			Rear	54.3±.67	38.5±.65	0.47	13.80	0.45±.012	11
		Density[1]	Front	2.6±.06	2.4±.06	0.33	1.50	0.35±.015	5
			Rear	2.7±.05	2.6±.04	0.35	1.81	0.28±.011	6
		Fineness	Side	23.9±.26	24.7±.28	0.41	14.43	0.43±.005	9
			Thigh	26.9±.32	28.2±.38	0.43	15.10	0.49±.015	9

[1] Centrigrams of clean wool per c.c. of staple

[2] Standard error.

[3] a and b are the coefficients necessary to the expression of linear regression.

There is a definite relationship for density between the adjacent samples taken at either age as shown by the highly significant regression and correlation coefficients in table 2. It is noted that the relationship between the two adjacent samples is considerably lower at yearling than at weanling age.

TABLE 2.—RELATIONSHIPS BETWEEN ADJACENT SAMPLES FOR FLEECE CHARACTERS

Breed	Number of animals	Characters	Age sampled	Mean		r	Regression of front on rear	Per cent reduction from standard deviation of mean to standard error of estimate
				Front	Rear			
Rambouillet	74	Length (cm.)	Weanling	2.4±.06[2]	2.3±.06[2]	0.89	0.79	58
			Yearling	5.7±.09	5.7±.09	0.88	0.80	50
		Clean (%)	Weanling	37.6±.95	37.0±.98	0.91	0.94	56
			Yearling	32.6±.54	34.7±.47	0.86	0.75	48
		Density[1]	Weanling	2.3±.04	2.3±.05	0.71	0.82	27
			Yearling	2.6±.04	2.7±.05	0.49	0.56	12
Corriedale	50	Length (cm.)	Weanling	6.1±.13	6.1±.11	0.76	0.66	34
			Yearling	9.3±.17	9.5±.16	0.93	1.00	59
		Clean (%)	Weanling	57.0±.69	55.4±.79	0.81	0.94	41
			Yearling	40.0±.75	42.9±.80	0.90	0.97	56
		Density[1]	Weanling	2.4±.05	2.3±.04	0.63	0.70	22
			Yearling	2.3±.06	2.4±.05	0.50	0.56	13
Columbia	51	Length (cm.)	Weanling	5.1±.10	5.2±.11	0.72	0.78	30
			Yearling	8.9±.16	9.2±.17	0.82	0.88	43
		Clean (%)	Weanling	55.9±.51	54.3±.67	0.85	0.85	47
			Yearling	41.0±.70	44.5±.65	0.69	0.64	19
		Density[1]	Weanling	2.6±.06	2.7±.05	0.68	0.65	26
			Yearling	2.4±.06	2.6±.04	0.55	0.39	15

[1] Centigrams of clean wool per c.c. of staple.
[2] Standard error.

The relationship for finess of fiber between the weanling and yearling side and thigh samples was not high. However, significant regression and correlation coefficients were found in every case except in the Rambouillet thigh samples. The reliability of predictions of yearling fineness from weanling fineness was slight with the exception of the Rambouillet thigh samples where it was very low. The low relationship in the Rambouillet thigh samples may result from a systematic error due to sampling a marginal location. The low relationship for fineness in general may be due to a slight genetic variation in fineness compared to length and clean yield as suggested by Lambert, *et al.* (1938).

In a comparison of the fineness of fiber between the side and thigh at both the weanling and yearling ages in the Rambouillets, results show a significant correlation of 0.38 and 0.43, respectively. The correlations for

fineness in the Corriedale and Columbia samples for weanling side and thigh were 0.05 and 0.03, respectively, and for the yearling side and thigh samples 0.05 and 0.04, respectively. The higher relationship in the Rambouillet fineness may be due to less variation within finer wool fleeces. This may be due to the greater variability possibly existing within the coarser wool fleeces produced by these breeds. Since a low relationship exists between the side and thigh samples of coarser wool they should be considered individually. Samples from Rambouillet sheep should be considered individually for fineness even though there was a significant relationship between the side and thigh samples at either age, so any great variation between these areas on the fleece may be detected.

Rambouillet and Corriedale weanling wool from both side and thigh was as coarse or coarser than yearling wool. However, the side and thigh samples from the Columbia weanling wool were finer than from the yearling wool which is not in accord with the findings from those reported in the preliminary study, where all weanling wool was found somewhat greater in mean diameter.

In order to compare results in this paper with those in the preliminary report a study was made of the means of the areas for weanling and yearling samples which had been done by Lambert, *et al.* (1938). The correlations were significant for each character studied and were as high or higher than those obtained by Lambert *et al.* (1938) in most cases.

In general the results of this study are in agreement with those of the preliminary report of Lambert, *et al.* (1938). It appears that length of staple and per cent of clean wool of the weanling may be used for predicting the outcome on the yearling fleece while fineness and density have but slight predictive values. Results in this paper are also in agreement with those of Terrill[3] who studied the relation between weanling and yearling fleece characteristics of 186 Rambouillet ewes. He found that fleece length had the highest relationship of weanling with yearling of the fleece characters studied. Highly significant but low correlations were also found by Terrill for fleece character score, fleece density score, density index, fineness at the side and fineness at the thigh between weanling and yearling.

The relationship between the average of the two weanling samples and the average of the two yearling samples, as measured by the correlation coefficients, although sometimes higher, was not significantly different from the correlation between one weanling sample and one yearling sample for each of the characters studied with the exception of fleece length in the Columbias. Significance of differences between correlation coefficients were

[3] Terrill, Clair E., Relationships among characters used in evaluating merit in weanling and yearling Rambouillet ewes. Unpublished data.

tested by the method given by Fisher (1936). This indicates that, with this one exception, little is gained by taking two samples rather than one at either age. In Columbias the reliability of predicting yearling fleece length from weanling fleece length is materially increased by taking four instead of two measurements.

In the practical application of the data presented it may be desirable to estimate the yearling value (Y) from the weanling value (X) using the formula $Y = a + Xb_{y.x}$. The a and b values are presented in table 1. For example if the weanling fleece length of a Rambouillet was 3.0 centimeters the predicted yearling length would be calculated as follows:

$$Y = 3.42 \text{ cm.} \pm (3.0 \text{ cms.})\ (0.96) = 6.30 \text{ centimeters}$$

The a values given in table 1 were calculated before the means were rounded and therefore will not check exactly with means given. It should be remembered that these formulae may not apply to cases where conditions are not comparable to those which obtain here.

Summary

It appears that length of staple and percentage of clean wool on the weanling may be used for predicting these characters in the yearling fleece. These characters give the most reliable results.

Fineness and density show some predictive value but in this study this value appears limited. It is pointed out that fineness determinations for side and thigh wool samples should be considered individually.

For practical purposes one sample was found to be as good as two for estimating percentage clean yield, density index and staple length. However, in the Columbias the reliability of predicting yearling fleece length from weanling fleece length is materially increased by measuring four samples instead of two.

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THE RELATIVE EFFICIENCY OF UREA AS A PROTEIN SUBSTITUTE IN THE RATION OF RUMINANTS[1,2]

B. Connor Johnson, Tom S. Hamilton, H. H. Mitchell and Willard B. Robinson
University of Illinois[3]

SINCE the publication of Weiske, Schrodt and von Danger (1879), indicating the possible importance of non-protein nitrogenous compounds as protein substitutes in ruminant nutrition, convincing evidence has been offered that such compounds are so utilized by ruminants, in all likelihood through the mediation of the flora and fauna of the rumen. Recent contributions of this nature, relative to urea, have been reported by Wegner, Booth, Bohstedt and Hart (1940) and Harris and Mitchell (1941a, 1941b).

However, there is very little information in the literature concerning the efficiency with which the ruminant utilizes dietary nitrogen in non-protein form. Harris and Mitchell (1941a) compared the biological values of urea and casein nitrogen for sheep at maintenance and sub-maintenance levels, and secured some data on the relative utilization of these two forms of nitrogen in covering the requirements of growth. This paper will report the results of nitrogen balance experiments on growing lambs, designed to compare the utilization of the nitrogen of urea, soybean oil meal and casein.

Experimental Methods

The experiments were concerned, first, with a determination of the proper protein level at which to make the comparisons of nitrogen utilization; second, with comparisons of urea, soybean oil meal (expeller process) and commercial casein; and third, with a test of the ability of the growing lamb to satisfy its requirements for nitrogen completely from a urea supplement added to a basal ration containing approximately 6 per cent crude protein on the dry basis.

These objectives were attained by means of nitrogen balance studies, similar in technical details and in equipment used to those previously reported by Harris and Mitchell (1941a). The collection periods were of 9 or 10 days duration, preceded by preliminary periods on the same respective rations lasting 6 or 7 days. The lambs were fed in pairs, each pair receiving isocaloric amounts,[4] within narrow limits, of the two rations being com-

[1] This investigation was made possible by the donation of funds to the University of Illinois by the E. I. DuPont de Nemours Company.

[2] A preliminary report of this investigation was presented before the Division of Agricultural and Food Chemistry of the American Chemical Society at the meeting at Atlantic City on September 8–12, 1941.

[3] Animal Nutrition Division, Urbana, Ill.

[4] Estimated equal amounts of metabolizable energy.

pared, excepting those cases in which orts remained from the final day's feed. In successive periods, the rations were reversed, so that each lamb received each of the experimental rations, while in one test a system of double reversal was used.

The subjects of the experiment were native grade wether lambs weighing from 50 to 80 lbs. initially. The rations were all modifications of a basal mixture containing 48 per cent of red top hay, 30 per cent of ground yellow corn, 20 per cent of corn molasses, 1 per cent of steamed bonemeal, 0.75 per cent of common salt, and 0.25 per cent of a fortified cod liver oil, to which, in the tests comparing different nitrogen supplements, 0.1 per cent of sodium sulfate was added as a source of sulfur for bacterial growth. The urea was generally added to this basal ration without substitution, since it does not contain available energy. The soybean oil meal and the casein were incorporated in the basal mixture at the expense of the corn molasses. In some of the tests, in order to equalize better the content of sugars in the comparative rations, the corn molasses in the urea ration was equated with that of the soybean meal or the casein ration, and an addition of corn starch employed to complete the ration.

The biological values of nitrogen, reported for the rations containing approximately 12 per cent crude protein equivalent, were estimated on the assumption of an endogenous nitrogen output in the urine of 1.231 gms. per m^2 of body surface (Ritzman and Colovos, 1930), and an output of metabolic nitrogen in the feces of 0.555 gm. per 100 gms. of dry matter consumed (Harris and Mitchell, 1941a).

Experimental Results

The data presented in table 1 related to the nitrogen metabolism of growing lambs receiving graded amounts of urea, equivalent roughly to 10, 12 and 14 per cent of crude protein on the dry matter basis. In periods 1 and 2, six of the eight permissible comparisons, between the different pair mates and between the two periods for the same lambs, indicate higher retentions of nitrogen on the higher level; the probability that fortuitous factors alone would produce as large or larger difference between the two rations is only 0.018 (Student, 1908). On the other hand, the data of periods 3 and 4, comparing 12 with 14 per cent protein equivalent, are quite indecisive. Of the twelve permissible comparisons, five indicated a larger retention of nitrogen on the lower nitrogen ration. It is interesting to note that the 12 per cent ration was distinctly more palatable to the lambs than the 10 per cent ration, while there was no noticeable difference in this respect between the rations containing 12 and 14 per cent protein equivalent.

Evidently, for the particular basal ration used in this experiment, the urea

supplements increased the growth-promoting value, as measured by nitrogen retention, certainly up to a nitrogen level of 10 per cent protein equivalent, but not beyond a nitrogen level of 14 per cent protein equivalent.

The apparent digestibility of nitrogen in all comparisons was the greater

TABLE 1.—THE EFFECT OF GRADED LEVELS OF UREA ON THE NITROGEN BALANCE OF GROWING LAMBS

Period number	Lamb number	Body weight	Crude protein in ration	Nitrogen intake		Apparent digestibility of nitrogen	Nitrogen balance		Estimated biological value of nitrogen
				Total per day	As urea		Total per day	Per cent of absorbed nitrogen	
		pounds	*per cent*	*grams*	*per cent*	*per cent*	*grams*	*per cent*	*per cent*
1	2611	49.5	9.73	11.21	40	52.0	1.81	31.0	—
	2572	48.5	11.30	12.76	50	62.6	2.54	31.8	67
	2513	76.5	9.73	14.01	40	51.7	0.56	7.7	—
	2688	74.5	11.30	15.95	50	65.3	1.31	12.5	53
2	2611	49.2	12.18	13.13	50	59.7	1.50	19.1	58
	2572	50.3	9.81	10.13	40	56.3	1.82	31.8	—
	2513	76.0	12.18	15.89	50	63.9	1.15	11.3	52
	2688	77.0	9.81	12.20	40	62.3	0.60	7.8	—
3	2640	56.5	11.41	11.58	50	64.8	1.53	20.3	60
	2588	57.5	13.31	13.51	57	69.2	1.11	11.9	—
	2465	52.2	11.41	11.58	50	62.9	1.15	15.8	58
	2470	54.2	13.31	13.51	57	69.0	1.87	20.1	—
	2481	54.7	11.41	13.29	50	62.7	2.14	25.7	63
	2447	53.0	13.31	14.10*	57	66.2	2.16	23.2	—
4	2640	57.2	13.95	13.25*	56	68.8	1.70	18.6	—
	2588	58.5	12.00	11.43*	49	65.1	1.81	24.3	63
	2465	54.5	13.95	13.67	56	68.9	2.62	27.7	—
	2470	56.3	12.00	11.76	49	66.0	1.67	21.5	59
	2481	55.2	13.95	13.67	56	69.5	1.72	18.1	—
	2447	54.3	12.00	11.43*	49	64.1	2.29	31.3	68

* Some food refused on last day of collection period.

for the higher-nitrogen ration, indicating a greater apparent digestibility of the products formed from urea in the paunch of the sheep than of the nitrogenous compounds of the basal ration.

Whether urea added to the basal ration containing 6 per cent of crude protein can promote protein synthesis in the paunch at a rate rapid enough to cover the demands of maximum growth in lambs, is revealed by the results tabulated in table 2. Here, using a double reversal system of feeding, com-

parisons were made with six lambs between two rations containing approximately 16 to 17 per cent of nitrogen, derived in the one case from urea to the extent of 65 per cent, and in the other case from urea to the extent of 46 to 47 per cent and from soybean meal to the extent of 18 per cent, the remainder in both rations being derived from the usual basal ration.

TABLE 2.—THE EFFECT OF A SUPPLEMENT OF SOYBEAN PROTEIN ON THE NITROGEN BALANCE OF GROWING LAMBS RECEIVING RATIONS CONTAINING A HIGH LEVEL OF UREA

Period number	Lamb number	Body weight	Crude protein in ration	Nitrogen intake			Apparent digestibility of nitrogen	Nitrogen balance	
				Total per day	As urea	As soybean		Total per day	Per cent of absorbed nitrogen
		pounds	per cent	grams	per cent	per cent	per cent	grams	per cent
5	2452	59.7	16.88	16.39	46.5	18	76.6	2.78	22.1
	2647	59	16.42	16.04*	64.5	—	73.1	1.97	16.8
	2520	66.7	16.88	16.39	46.5	18	76.4	3.19	25.5
	2544	66.5	16.42	15.25*	64.5	—	77.1	2.23	18.9
	2651	58	16.88	16.39	46.5	18	76.1	2.73	21.9
	2438	60.7	16.42	16.32	64.5	—	75.0	2.37	19.4
6	2452	62	15.47	15.48	63.5	—	73.7	2.06	18.1
	2647	61.7	16.61	16.22	46	17.5	73.9	2.43	20.3
	2520	68.7	15.47	15.48	63.5	—	72.5	2.03	18.0
	2544	67.2	16.61	15.85*	46	17.5	75.7	2.45	20.5
	2651	59	15.47	15.48	63.5	—	72.5	1.77	15.8
	2438	60	16.61	16.22	46	17.5	74.4	2.10	17.4
7	2452	63.2	17.01	16.39	47.2	18.4	75.2	2.36	19.1
	2647	63	16.52	16.25	65.6	—	73.0	1.77	14.9
	2520	70.5	17.01	16.39	47.2	18.4	75.8	3.04	24.5
	2544	68.7	16.52	16.25	65.6	—	75.6	2.46	20.0
	2651	61	17.01	16.39	47.2	18.4	75.4	2.26	18.3
	2438	63.3	16.52	16.25	65.6	—	74.9	1.93	15.8

* Some feed refused on last day of collection period.

The apparent digestibility of the nitrogen in the two rations averaged 75.5 per cent for the soybean-containing ration, and 74.2 per cent for the urea ration. In 17 of the 21 permissible comparisons, the nitrogen of the soybean ration was the better digested as measured by the ordinary coefficients of digestibility, and this difference, though slight, is evidently statistically significant.

The nitrogen balances, expressed as percentages of the apparent absorbed

nitrogen, to allow for slight differences both in nitrogen intake and in the digestibility of nitrogen, favored the ration containing soybean meal in 20 of the 21 permissible comparisons, between paired lambs in the same period, and the same lambs in different (but adjacent) periods. This is a highly significant difference. Hence, it may be concluded, first, that the protein of soybean meal is better digested than the products formed from urea in the paunch; and second, that urea added to the basal ration used cannot promote protein synthesis by the symbiotic microorganisms at a rate rapid enough to cover the nitrogen requirements of the growing lambs used in these studies.

Since at these high levels of urea feeding, there is a possibility that the significance of the nitrogen balance as a measure of nitrogen retention in growth may be impaired by a piling up of urea as such in the blood and tissues, the non-protein nitrogen of the blood was determined in the six lambs in period 7, both at the start and at the termination of the collections. The values averaged 34.7 mgms. per 100 cc. of blood in both series of analyses, showing that urea, even at this high level of feeding, does not accumulate in the blood, and presumably, in view of the rapid diffusion of urea, not in the tissues also. The finding of Harris and Mitchell (1941a) that urea is not excreted in appreciable amounts through the skin of sheep was confirmed, but in this connection it was shown that wool will rather readily yield nitrogen in soluble form to the mild reagents used in washing it.

On the basis of the experimental results reported in table 1, the comparisons between the utilization in growth of the nitrogen of urea and of soybean meal, and of urea and of casein, were carried out by adding to, or incorporating in, the basal ration amounts of the test supplements sufficient to produce a total nitrogen content equivalent to approximately 12 per cent crude protein. The comparison between urea and soybean nitrogen is the subject of table 3. In periods 8 and 9, the soybean meal was incorporated in its ration by the replacement of isocaloric amounts of corn molasses. In periods 10 and 11, the urea and soybean rations contained equal amounts of molasses (9 per cent), 9.6 per cent of corn starch and 1.4 per cent of wood flour in the urea ration balancing 11 per cent of soybean oil meal in the soybean ration.

The apparent digestibility of the nitrogen in periods 8 and 9, in which the rations contained unequal amounts of sugars (molasses) averaged 62.8 per cent for the soybean meal ration and 64.5 for the urea ration. Of the ten permissible comparisons, omitting the abnormal case of lamb 2688 in period 8, all favored the urea ration. However, in periods 10 and 11, when the rations contained equal amounts of sugar, the apparent digestibility of the nitrogen averaged 61.0 per cent for the soybean ration and 61.1 per cent for the urea

TABLE 3.—COMPARISON OF THE AVAILABILITY OF UREA NITROGEN AND SOYBEAN NITROGEN FOR GROWING LAMBS, WITH UNEQUAL (PERIODS 8 AND 9) AND EQUAL (PERIODS 10 AND 11) INTAKES OF MOLASSES

Period number	Lamb number	Body weight	Crude protein in ration	Nitrogen intake			Apparent digestibility of nitrogen	Nitrogen balance		Estimated biological value of nitrogen	Apparent digestibility of cellulose
				Total per day	As urea	As soybeans		Total per day	Per cent of absorbed nitrogen		
		pounds	*per cent*	*grams*	*per cent*	*per cent*	*per cent*	*grams*	*per cent*	*per cent*	*per cent*
8	2470	63	11.54	14.46	48	—	64.9	2.37	25.3	62	43.1
	2465	63	12.12	14.35	—	48.4	63.8	2.30	25.2	61	50.2
	2572	63.5	11.54	14.46	48	—	64.3	2.64	28.3	64	45.1
	2611	61.7	12.12	14.35	—	48.4	62.7	2.45	27.2	63	50.3
	2513	83.7	11.54	14.46	48	—	63.0	1.03	11.3	55	45.3
	2688	78.2	12.12	8.34*	—	48.4	71.5	−2.06	—	—	—
9	2470	66	12.04	14.59	—	47.6	63.8	2.97	31.8	66	52.6
	2465	66.5	11.96	15.04	46.2	—	64.9	2.79	28.5	63	35.0
	2572	67.5	12.04	14.59	—	47.6	63.2	2.66	28.8	64	51.2
	2611	64.7	11.96	15,04	46.2	—	63.6	2.75	28.7	64	44.6
	2513	85	12.04	14.59	—	47.6	60.5	2.08	23.6	64	55.5
	2688	78.2	11.96	15.04	46.2	—	66.2	2.93	29.5	65	39.7
10	2588	62	11.64	11.82	45.3	—	64.2	2.24	29.5	67	44.2
	2640	60.2	12.25	13.35	—	43.3	65.5	2.03	25.1	62	55.6
	2481	73.7	11.64	15.19	45.3	—	61.8	2.18	23.3	62	53.7
	2447	71.2	12.25	15.88	—	43.3	61.6	2.87	29.3	65	58.0
	2651	74.5	11.64	16.88	45.3	—	58.4	2.59	26.2	64	43.1
	2438	70.5	12.25	17.65	—	43.3	60.7	3.60	33.6	66	46.2
11	2588	64.7	11.31	11.28	—	44.2	62.4	1.05	14.9	60	52.2
	2640	62.7	11.57	11.64	46	—	64.8	0.71	9.4	54	51.7
	2481	77	11.31	14.50	—	44.2	61.1	1.77	20.0	61	52.9
	2447	74.7	11.57	14.47*	46	—	57.0	1.30	15.8	62	51.8
	2651	77.5	11.31	11.65*	—	44.2	54.6	0.26	4.1	74	40.7
	2438	77.5	11.57	16.64	46	—	60.3	2.32	23.1	62	46.3

* Some food refused on last day of collection period.

ration, and the difference between the two is evidently insignificant. The differential occurrence of sugars (molasses) in the rations seems to have determined the difference in the apparent digestibility of nitrogen in periods 8 and 9.

The apparent digestibility of cellulose was also measured in periods 8 to

11, inclusive, using the analytical method of Crampton and Maynard (1938) for cellulose in feed and feces. The results are summarized in the last column of table 3. In the periods (8 and 9) in which the comparative rations contained unequal amounts of molasses, higher digestion coefficients of cellulose were obtained consistently for the ration with the lower content of molasses, i.e., the soybean ration, the average coefficients, omitting lamb 2688 in period 8, being 52.0 for the soybean ration and 42.1 for the urea ration. In periods 10 and 11, in which the molasses contents of the comparative rations were equalized, the digestibility of cellulose was still higher for the soybean ra-

TABLE 4.—COMPARISON OF THE AVAILABILITY OF UREA NITROGEN AND CASEIN NITROGEN FOR GROWING LAMBS

Period number	Lamb number	Body weight	Crude protein in ration	Nitrogen intake			Apparent digestibility of nitrogen	Nitrogen balance		Estimated biological value of nitrogen	Apparent digestibility of cellulose
				Total per day	As urea	As casein		Total per day	Percent of absorbed nitrogen		
		pounds	*per cent*	*grams*	*per cent*	*per cent*	*per cent*	*grams*	*per cent*	*per cent*	*per cent*
12	2465	72	11.40	13.05	48.7	—	62.3	2.09	20.8	66	43.5
	2470	71.5	11.71	13.22	—	50.1	65.4	1.90	19.0	62	40.7
	2452	79	11.40	13.05	48.7	—	65.5	1.88	18.8	63	41.8
	2647	74	11.71	13.22	—	50.1	66.1	2.05	20.5	62	44.9
	2572	76.3	11.40	13.05	48.7	—	67.0	1.73	17.3	61	54.5
	2611	70.7	11.71	13.22	—	50.1	63.1	1.97	19.7	63	48.0
13	2465	72.5	11.34	12.84	—	49.2	62.9	1.25	12.5	59	45.0
	2470	72.2	11.48	12.72	49.9	—	62.2	2.00	20.0	66	37.3
	2452	80.2	11.34	12.84	—	49.2	66.9	1.35	13.5	58	48.1
	2647	75.5	11.48	12.72	49.9	—	63.1	2.22	22.2	67	44.9
	2572	77	11.34	12.84	—	49.2	66.4	1.33	13.3	58	51.3
	2611	72	11.48	12.72	49.9	—	58.5	1.69	16.9	66	42.6

tion, but the average coefficients were much closer together, 53.0 and 48.5, (omitting the abnormal case of lamb 2651 in period 11) although the difference between averages, considering all ten permissible pairings, was also statistically significant ($P=0.007$). These results confirm the conclusion of Mitchell, Hamilton and Haines (1940), and of Hamilton (1942), that, in ruminants, supplements of soluble sugars depress the digestibility of the fibrous constituents of the basal feeds, probably by diverting bacterial action from the less to the more readily fermentable carbohydrates. The results also indicate clearly that the cellulose of soybean meal is more digestible than that of the wood flour in the urea ration.

The utilization of nitrogen in metabolism, as measured either by the nitrogen balance expressed as a percentage of the apparent absorbed nitrogen or by the estimated biological value, was not statistically different for the two experimental rations, the nitrogen balances averaging 25.95 and 23.24 per cent for the soybean and the urea rations, respectively, and the biological values 63.2 and 62.0.

In comparing the utilization of the nitrogen of urea with that of a technical grade of casein, the two experimental rations contained equal proportions of molasses (11.87 per cent), while the energy of the casein was balanced in the urea ration by the incorporation of isocaloric amounts of corn starch. The results of the comparison, carried out through two experimental periods, are summarized in table 4. The digestibility of the nitrogen in the casein ration, averaging 65.5 per cent, was higher than that in the urea ration, averaging 63.1 per cent, and the difference was statistically significant ($P=0.008$). The digestibility of the cellulose was also somewhat higher in the casein ration, averaging 46.3, as compared with 44.1 per cent, but the difference is hardly significant statistically ($P=0.069$).

The utilization of the urea nitrogen in metabolism was slightly, but distinctly, higher than the utilization of the casein nitrogen, whether measured by the nitrogen balance expressed as a percentage of the apparent absorbed nitrogen (averaging 19.33 and 16.42 per cent, respectively, with $P=0.018$), or by the estimated biological value (averaging 64.83 and 60.33, respectively, with $P=0.0003$). These results differ from those of Harris and Mitchell, who found a definite superiority of casein over urea in the utilization of its nitrogen for maintenance (1941a) and for growth (1941b), although in the latter case the data on casein were secured with only one lamb. The discrepancy may be explained possibly on the basis of a difference in the character either of the basal ration or the sulfur supplement fed (inorganic sulfate in the present experiments and flowers of sulfur in the earlier ones), or of the samples of casein tested.

The similarity in the metabolic utilization of the nitrogen of urea, of soybean oil meal and of casein by the ruminant animal, as revealed in the experiments just reported are consistent with the theory that a considerable proportion of the protein ultimately utilized by the ruminant is microorganismal protein, regardless of the nature of the nitrogen compounds contained in the ration as consumed. The theory receives some support from the slight differences that have frequently been reported in the biological values of protein supplements tested with sheep, and of the frequency of biological values approximating 60 when the nitrogen level in the ration is equivalent to 10 to 12 per cent of crude protein. The following tabulation illustrates this point:

Source of protein	Average biological value	Authority
Corn, alfalfa hay	59	Miller and Morrison (1939)
Corn, alfalfa hay, timothy hay	60	
Corn, alfalfa hay, timothy hay, soybean meal	64	
Corn, timothy hay, soybean meal	62	
Corn, timothy hay, soybean meal	62	Miller, Morrison and Maynard (1937)
Corn, timothy hay, linseed meal	63	
Corn, timothy hay, corn gluten meal	64	
Corn, corn stover, soybean meal	58	
Corn, corn stover, linseed meal	56	
Corn, corn stover, corn gluten meal	58	
Corn silage, urea	60	Harris and Mitchell (1941b)
Red top hay, corn, urea	63	This report
Red top hay, corn, soybean meal	63	
Red top hay, corn, casein	60	
Alfalfa hay	60	Smuts and Marais (1938)

However, Turk, Morrison and Maynard (1934) obtained biological values of 81 for red clover protein, 79 for alfalfa protein, 80 for the proteins in red clover and corn, and 77 for the proteins in alfalfa and corn, at a protein level of 10 to 11 per cent.

The theory above discussed is of sufficient scientific interest and practical importance to warrant further study, which is at present under way in this laboratory.

Summary and Conclusions

Digestion and metabolism experiments have been carried out on sixteen growing lambs for the purpose mainly of comparing the biological utilization of the nitrogen of urea, soybean oil meal and of casein. These nitrogenous supplements were added to, or incorporated in, a basal ration containing approximately six per cent of crude protein derived from red top hay and from corn. The results obtained appear to justify the following conclusions:

1. The addition of urea to the basal ration in amounts to produce the equivalent of 12 per cent of crude protein on the dry basis induces a retention of nitrogen in growing lambs that cannot be bettered by further urea additions, but can be bettered by raising the true protein content of the ration. Hence, under the conditions of these experiments, it appears that the conversion of urea in the paunch does not proceed at a sufficiently rapid rate to cover the protein requirements of the growing lamb.

2. Supplements of available sugars in the form of corn molasses depress the digestibility of the cellulose of the ration, but enhance the utilization in digestion of urea nitrogen.

3. The nitrogen in the products formed in the paunch of the sheep from ingested urea is less well digested than the nitrogen of casein.

4. The nitrogen in the products formed in the rumen from urea is as well utilized in metabolism as the nitrogen of soybean oil meal and somewhat better utilized than the nitrogen of casein.

5. From the fact that, in this experiment and in others previously reported on sheep, the biological value of the nitrogen of rations containing 10 to 12 per cent of crude protein (N×6.25) generally varies only within a few per cent from 60, it is an attractive theory, which needs more direct confirmation however, that a considerable proportion of the protein ultimately utilized by the ruminant is microorganismal protein, regardless of the nature of the nitrogenous compounds contained in the ration as consumed.

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DIRECT METHODS OF COMPUTING RATIONS[1]

BURCH H. SCHNEIDER[2]
West Virginia University[3]

Introduction

THE MOST commonly used method of computing rations is by "trial-and-error." A trial ration is computed, and shifts made in the proportions of feeds until a close approximation to the desired result is obtained. There are many circumstances in which a direct method could be used to reduce the time and effort involved in calculations. With a direct method, by a single mathematical process with given feeds, the correct and exact answer can be obtained.

The object of this paper is to present a description of direct methods of calculating rations. It is felt that this presentation will be of value to students and teachers in livestock feeding courses and to all animal husbandry workers who find it necessary to calculate rations. Also, it is hoped that the material presented will stimulate further efforts in this field.

Problem

Various methods of computing rations are described briefly below. The following problem is used in all cases: Calculate a ration for growing, fattening pigs weighing 75 lb., using corn and trio mixture.

Requirements

The daily requirements given by Morrison (1937) are as follows:

Dry matter lb.	Digestible protein lb.	Total digestible nutrients lb.	Nutritive ratio 1:
2.9-3.9	0.43-0.52	2.6-3.5	5.3 5.8

It may be decided arbitrarily to feed the widest nutritive ratio and the lowest T. D. N. permitted by the above feeding standards. Such a ration would probably be the cheapest. Other possibilities would be the narrowest

[1] Published with the approval of the Director, West Virginia Agricultural Experiment Station, as Scientific Paper No. 274.

[2] The author is indebted to Ralph W. Phillips and Bradford Knapp, Jr., of the Bureau of Animal Industry, Beltsville, Maryland, for helpful assistance in the preparation of this paper.

[3] Animal Husbandry Department. Morgantown, W. Va.

nutritive ratio and lowest T. D. N.; widest nutritive ratio-highest T. D. N. and narrowest nutritive ratio-highest T. D. N.

Composition of the Feeds Used.

The composition of the trio mixture is calculated in the usual way. Corn is taken directly from the table in Morrison (1937).

	Dry matter lb.	Digestible protein lb.	Total digestible nutrients lb.	Nutritive ratio 1:
50 lb. tankage (60%)	46.1	28.2	39.0	
25 lb. linseed oil meal	22.8	7.6	19.6	
25 lb. ground alfalfa	22.6	2.6	12.6	
100 lb. TRIO MIXTURE	91.5	38.4	71.2	.85
100 lb. No. 2 CORN	85.2	7.1	80.6	15.3

Direct Methods Computation

The various methods of computation of rations directly are illustrated below, and designated as methods A to F, respectively.

Method A.

This is a method recently developed and described briefly by Schneider (1942). (1) Convert the desired nutritive ratio and the nutritive ratio of each of the two feeds (or groups of feeds) into a new value *per cent protein in the T. D. N.*, in either of two ways:

$$\frac{1}{\text{Second factor of the nutritive ratio} + 1} \times 100$$

or

$$\frac{\text{Digestible protein}}{\text{T. D. N.}} \times 100 = \text{per cent protein in the T. D. N.}$$

The first of these is necessary to compute the per cent protein in the T. D. N. in the feeding standards, but either formula may be used to calculate the percentages for feeds, although the latter is more accurate.

Solving the problem stated above, feeding the widest nutritive ratio and the minimum T. D. N. given in the feeding standards, the calculations are as follows:

For the desired nutritive ratio:

$$\frac{1}{5.8+1} \times 100 = 14.7\%$$

For corn:

$$\frac{7.1}{8c.6} \times 100 = 8.8\%$$

For trio mixture:

$$\frac{38.4}{71.2} \times 100 = 53.9\%$$

(2) Using the above percentages in Pearson's square (as in standardizing cream) the following computations are made:

53.9 a

14.7

8.8 b

a+b

where $a = 14.7 - 8.8$ and $b = 53.9 - 14.7$, we obtain

53.9 5.9 parts T. D. N. from trio mixture

14.7

8.8 39.2 parts T. D. N. from corn

45.1 total parts

(3) Multiply the desired per cent protein in the T. D. N. by the desired pounds of T. D. N. to find out if the resulting pounds of digestible protein fall within the requirements stated in the feeding standards:

$$14.7 \times 2.6 = 0.382 \text{ lb. digestible protein.}$$

As this amount of digestible protein is outside the standards it must be corrected for in the next equation, by multiplying by the fraction 0.43/0.382, the numerator of which is the nearest requirement for digestible protein stated in the standards, and the denominator the pounds of digestible protein obtained by the latter calculation. If however, this product of the desired per cent protein in the T. D. N. times the desired T. D. N. falls within

the requirements given in the feeding standards, this fraction can be omitted. (4) Divide the desired T. D. N. requirement by the total parts obtained in (2) above, multiply by the fraction obtained in (3) if so indicated by the calculations illustrated in (3), and multiply by 100, as follows:

$$\frac{2.6}{45.1} \times \frac{0.43}{0.382} \times 100 = 6.49\%,$$ the percentage the daily requirement is of the total parts.

(5) Using the parts T. D. N. from corn and from trio mixture obtained in (2) and the percentage obtained in (4), compute as follows:

$$39.2 \times 6.49\% = 2.54 \text{ lbs. T. D. N. from corn.}$$

$$5.9 \times 6.49\% = 0.383 \text{ lb. T. D. N. from trio mixture.}$$

(6) Using the figures obtained under (5) and the amounts of T. D. N. in one pound of corn and one pound of trio mixture, compute the ration as follows:

$$\frac{2.54}{.806} = 3.15 \text{ lbs. corn.}$$

$$\frac{0.383}{.712} = 0.54 \text{ lb. trio mixture.}$$

Method B

This method has been in use for many years and the originator is not known to the author.

(1) Determine the excess carbohydrates equivalent (carbohydrates + 2.25 × fat) in corn as follows:

(a) % digestible protein in corn × desired nutritive ratio.
$7.1 \times 5.8 = 41.2$ carbohydrates protein will balance.

(b) T. D. N. − digestible protein = carbohydrate equivalent.
$80.6 - 7.1 = 73.5$ carbohydrate equivalent in corn.

(c) Carbohydrate equivalent in corn − carbohydrates protein in corn will balance.
$73.5 - 41.2 = 32.3$ excess carbohydrate equivalent in corn.

(2) Determine the excess digestible protein in the trio mixture, as follows:

(a) digestible protein in trio mixture desired nutritive ratio
$38.4 \times 5.8 = 222.7$ carbohydrate equivalent protein will balance.

(b) T. D. N. − digestible protein = carbohydrate equivalent.
$71.2 - 38.4 = 32.8$ carbohydrate equivalent in trio mixture.

(c) Carbohydrates protein will balance − carbohydrate equivalent in trio mixture.

222.7 − 32.8 = 189.9 lbs. carbohydrate equivalent that excess protein in trio mixture will balance.

(3) Determine the proportion in which the two feeds should be fed, using figures obtained under (1) and (2).

$$\frac{189.9}{32.3} = 5.88 \text{ parts of corn to one part of trio mixture.}$$

(4) Compute the content of 100 lbs. of mixture:

	Digestible Protein	Total Digestible Nutrients
588 lbs. corn	41.7	473.9
100 lbs. trio mixture	38.4	71.2
688 lbs. total	80.1	545.1
100 lbs. contains	11.6	79.2

(5) Determine the number of pounds of corn and trio mixture to feed.

$$\frac{\text{Pounds of digestible protein required daily}}{\text{Amount of digestible protein in 1 pound of feed}}$$

$$\frac{0.43}{0.116} = 3.71 \text{ lbs. of corn and trio mixture.}$$

$$\frac{3.71}{\text{Ratio of corn to trio mixture}} = \frac{3.71}{6.88} = .54 \text{ lb. trio mixture}$$

3.71 − 0.54 = 3.17 lbs. corn.

Method C.

This method devised by Willard (1902) has been used by some workers in the field.

(1) Find the protein equating factor (P. E. F.) for corn by dividing 100 by the per cent digestible protein in corn, as follows:

$$\frac{100}{7.1} = 14.08.$$

(2) Find the P. E. F. for trio mixture by dividing 100 by the per cent digestible protein in trio mixture, as follows:

$$\frac{100}{38.4} = 2.60$$

(3) Determine the proportions of the two feeds as follows:

(a) Subtract the nutritive ration of trio mixture from the desired nutritive ratio and multiply by the P. E. F. of corn to determine the pounds (or parts) of corn, as follows:

$$(5.8 - .85) \times 14.08 = 69.7 \text{ lbs. (or parts) of corn.}$$

(b) Subtract the desired nutritive ratio from the nutritive ratio of corn and multiply by the P. E. F. of the trio mixture, as follows:

$$(10.3 - 5.8) \times 2.60 = 11.8 \text{ lbs. (or parts) of trio mixture.}$$

(c) Divide the parts of corn by the parts of trio mixture to get the ratio of corn to trio mixture.

$$\frac{69.7}{11.8} = 5.91 \text{ lbs. of corn to 1 lb. of trio mixture.}$$

(4) The pounds of each feed can be computed as in (4) and (5) under Method B.

Method D.

This method was developed by Phillips[4] as an alternative to the methods given above.

(1) Subtract desired nutritive ratio from nutritive ratio of corn and multiply the difference by the per cent digestible protein in corn.

$$(10.3 - 5.8) = 31.95$$

(2) Subtract nutritive ratio of trio mixture from desired nutritive ratio and multiply by per cent digestible protein in trio mixture.

$$(5.8 - 0.85)\ 38.4 = 190.08$$

(3) Determine the proportion of the two feeds as follows:

$$\frac{190.08}{31.95} = 5.95 \text{ parts of corn to 1 part of trio mixture}$$

[4]Private communication from Ralph W. Phillips (1942).

(4) The pounds of each feed can be computed as in (4) and (5) under Method B.

Method E.

This method is a modification of the above methods (except method A) and was developed by Knapp.[5]

(1) Subtract the desired nutritive ratio from the nutritive ratio of corn and divide by the per cent digestible protein in the trio mixture:

$$\frac{10.3-5.8}{3.84}=.117$$

(2) Subtract the nutritive ratio of the trio mixture from the desired nutritive ratio and divide the per cent of digestible protein in corn:

$$\frac{5.8-0.85}{7.1}=.697$$

(3) Determine the proportion of the two feeds as follows:

$$\frac{.697}{.117}=5.96 \text{ parts corn to 1 part of trio mixture.}$$

(4) The pounds of each feed can be computed as in (4) and (5) under method B.

Discussion

The above methods all have two points in common: (1) They deal with two feeds (or two feed mixtures, or one individual feed and one feed mixture as in the example given). (2) One feed or feed mixture must have a wider nutritive ratio and the other must have a narrower nutritive ratio than that of the desired ration.

The chief difference in the methods is that method A is based on the *per cent protein in the T. D. N.*

All of the methods presented may be challenged regarding their applicability with rations consisting of a number of feeds containing both concentrates and roughages. It appears that the best way to compute rations is by placing the feeds in two groups, or one feed may be taken alone and all the other feeds taken as a group. Actually mixing the feeds as in the trio mixture shown in the example given in this paper is not necessary. In grouping the feeds it may be well to make up each group to contain the desired proportion

[5] Private communication from Bradford Knapp, Jr. (1942).

of roughages to concentrates. Thus the final ration will not contain too many or too few pounds of dry matter.

Willard (1902) presents a method in which a number of feeds in a ration are taken in several pairs. If there is an odd number of feeds, one may be taken twice. This is as effective in computing the parts of each feed as taking the feeds in two groups, except that there is no guarantee that the ration which supplies the desired nutritive ratio with any possible selection of high and low protein feeds will give the right proportion of concentrates and roughages. If, with the Willard pairing method, both nitrogenous and carbonaceous roughages are used, they may be paired, and thus the correct proportion of concentrates and roughages taken. However, this latter process may also be criticized, as it is not necessary that the protein be balanced within the concentrates and within the roughages each taken separately, but the balance should be rather within the ration as a whole for economy and the best nutrition.

An adequate method must supply the correct value for each of the following: dry matter, digestible protein, T. D. N. and nutritive ratio. While the importance of minerals and vitamins is recognized, a complete numerical standard for them has not been devised. The dry matter requirement in the feeding standard is to insure that a correct proportion of roughages and concentrates is supplied, i.e., that the nutrients are supplied in enough but not in too much dry matter. Protein is considered in all standards because of its peculiar place in metabolism. The number of pounds of total digestible nutrients is a measure of energy. The earlier Wolf-Lehman feeding standard gave separate values for carbohydrates and fats, but T. D. N. is a very useful simplification. The nutritive ratio represents the proportion between protein and the quantity of other energy-supplying constituents, all expressed on an equi-calorific basis. This relationship may also be expressed by the value "per cent protein in the T. D. N." presented in method A.

Of the above direct methods of calculating rations, none provides a method of calculating the amount of feeds to provide the correct number of pounds of dry matter. In method A the values for digestible protein, T. D. N., and nutritive ratio are used in the calculations. In methods B, C, D, and E only the figures for nutritive ratio and digestible protein are used. T. D. N. or carbohydrates (including fat $\times 2.25$) could be used in the calculations in B (4) and B (5) as well as the digestible protein which is used in the example and would give identical results. These methods would be more applicable if a single value represented the standard requirement for each digestible protein, T. D. N. and nutritive ratio, instead of the minimum and maximum values as expressed in Morrison's (1937) feeding standards.

Methods B, C, D and E are algebraically the same. They may all be ex-

pressed more simply, but this may be criticized for not developing the process logically step by step. The following is a simplified formula for the latter four methods and is the same as method D expressed in its simplest form:

$$\textit{Method F}\quad \frac{(R-R_2)P_2}{(R_1-R)P_1} = \text{Ratio of Cabonaceous to Nitrogenous Feed,}$$

in which R = desired nutritive ratio, R_1 = nutritive ratio of the carbonaceous feed, R_2 = nutritive ratio of the nitrogenous feed, P_1 = % digestible protein of the carbonaceous feed, and P_2 = % digestible protein of the nitrogenous feed. The difference between method B and methods C, D, and E is that in method B carbohydrate equivalent (digestible carbohydrates +2.25 × digestible fat) is obtained by deducting the per cent digestible protein from the T.D.N. while in methods C, D, and E it is obtained by multiplying the nutritive ratio by the per cent digestible protein. It would appear that substitutions in the latter simplified formula would be better than the more elaborate development of essentially the same process as presented in each of the methods B to E.

Substituting in formula F, we have the following:

$$\frac{(5.8-.85)38.4}{(10.3-5.8)7.1} = 5.95 \text{ parts of corn to } 1.00 \text{ part of trio mixture.}$$

It should be pointed out that the slight discrepancy between the ratios of corn to trio mixture found with the various methods may be corrected by carrying out the calculations to more decimal places. This has not been done as an effort has been made to make the processes practical rather than to obtain identical numerical values.

These methods would require no more tabular material than the present methods used. It would be possible to reduce by one half the mass of data in the requirements given in the feeding standards if only one value were given in each case instead of maximum and minimum values between which one endeavors to adjust a ration by trial-and-error methods. Method A would require no more columns in a table than the other methods if the value "per cent protein in the T. D. N." were used instead of nutritive ratio. It is similar to per cent protein calories in concept and from the standpoint of fundamental nutrition theory has advantages over the nutritive ratio. Owing to the inter-convertibility of proteins, fats, and carbohydrates in energy metabolism and since proteins contribute to the energy value of feeds as a whole, as well as being used for specific protein functions, the relationship (expressed as a percentage) of digestible protein to the total nutritive energy

is a more logical, as well as a more convenient, method of statement than the traditional nutritive ratio which relates digestible protein only to the energy value of digestible fats and carbohydrates. Also, Pearson's square is familiar to many students since it is used in the standardization of cream.

Summary

Six methods of computing livestock rations which eliminate part or all of the trial-and-error element are presented. The first, method A, makes use of a value, the percentage of digestible protein in the T. D. N. The Pearson square, commonly used in standardizing cream, is employed and the pounds of T. D. N. from each of two feeds or groups of feeds is computed. From the pounds of T. D. N. from each source the pounds of each feed can be calculated.

Methods B, C, D and E are summarized in method F which is as follows:

$$\frac{(R-R_2)P_2}{(R_1-R)P_1} = \text{Ratio of carbonaceous to nitrogenous feed}$$

in which R = desired nutritive ratio, R_1 = nutritive ratio of the carbonaceous feed, R_2 = nutritive ratio of the nitrogenous feed, P_1 = % digestible protein of the carbonaceous feed and P_2 = % digestible protein of the nitrogenous feed.

An example ration for a fattening growing pig is computed, using trio mixture and corn.

Direct methods of computation have been found useful in teaching students whose rapid progress is impeded by the trial-and-error method. Also they are helpful in grading students' papers to determine the extreme amounts of feeds possible within the feeding standards. Also, they can be used to compute exact experimental rations.

These methods need to be tried out under many conditions. It is hoped that improved modifications may be forthcoming from readers, and that a best method free from all trial-and-error processes and applicable to all conditions may be developed ultimately.

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PHENOTHIAZINE AS AN ANTHELMINTIC FOR SHEEP

V. E. Whitehurst, Jr., and Leonard E. Swanson[1]
Florida Agricultural Experiment Station

AN EXPERIMENTAL flock of sheep has been maintained at the North Florida Experiment Station, Quincy, since 1933. A permanent pasture consisting largely of carpet grass was established to afford grazing for the sheep. During the first year no losses occurred that could be attributed to parasitic infestation. When the sheep began grazing on the permanent pasture it was hoped that through rotation of improved permanent pastures that internal parasites could be controlled. After grazing on the improved pasture area for several months losses began to occur in both lambs and mature sheep. Post mortem examinations revealed the presence of large numbers of internal parasites.

A systematic program for drenching the sheep was inaugurated. The sheep, including the lambs, were drenched every 28 days with a 1 per cent solution of copper sulphate and nicotine sulphate. The results obtained at first from drenching with these drugs were encouraging; however, losses continued to occur and began to increase even though treatment was given every month. It was finally decided to administer the copper sulphate-nicotine sulphate solution every two weeks, in an effort to control the parasites. It was found that losses from parasites continued at a high level when the sheep were treated every two weeks. The flock was kept on permanent pastures during these studies.

Assuming that the permanent pastures were the source of continued reinfestation, it was deemed wise to abandon these pastures. With the elimination of the permanent pastures it was necessary to plan a new grazing program for the sheep. Accordingly, a system of grazing crops was planned which included green oats for winter and spring grazing, millet, Sudan grass and soybeans, for summer grazing, and cowpeas and corn fields for fall grazing. In making use of this system of grazing whereby annual crops were used in rotational grazing, and in which the soil was turned several times each year in breaking the land and cultivating the crops, it was thought that the internal parasites could be controlled, hence the dosing with the copper sulphate and nicotine sulphate solution was discontinued.

After using the system of annual crops for approximately two years, losses continued to be heavy and it was realized that dosing with an anthelmintic would be necessary if the flock was to be maintained.

[1] The authors are Assistant Animal Husbandman, North Fla. Exp. Sta., Quincy, and Parasitologist, Florida Agr. Exp. Sta., Gainesville, respectively.

Habermann and Hunt (1940) found that a 1 per cent solution of copper sulphate was ineffective against parasitism in a ram, even though the ram was treated routinely. These workers found that "twenty five grams of commercial phenothiazine was very effective in removing the nematodes from the gastro-intestinal tract of a sick, heavy parasitized ram." Harwood, Habermann, and Jerstad (1939) found that commercial phenothiazine was effective in removing 76.7 per cent of the hookworm and 90.9 per cent of the nodular worms in a lot of eight sheep. The drug appeared to be 100 per cent effective against the stomach thread worms and fairly effective against the removal of the wire worms found in the stomach. Later work by Habermann, Harwood and Hunt (1940) showed that 25 grams of crude, unconditioned phenothiazine was as effective in the removal of gastro-intestinal parasites in sheep as was the recrystallized drug. From the results obtained by the use of phenothiazine, these workers were lead to believe that this drug was less effective in sheep that showed symptoms of parasitism than it was in healthy animals.

Method of Procedure

Post mortem examinations were held on six sheep that showed symptoms of advanced parasitism. As a result of these examinations it was determined that the sheep were infested with wire worms (*Haemonchus contortus*), thread worms (*Ostertagia circumcincta*) and bankrupt worms (*Trichostrongylus spp.*) in the true stomach; hook worms (*Bunostomum trigonocephalum*), small intestinal thread worms (*Cooperia spp.*), and tape worms (*Moniezia spp.*) in the small intestine and nodular worms (*Oesophagostomum columbianum*) and whip worms in the large intestine. As a result of these findings it was decided to use phenothiazine as an anthelmintic, and to determine the efficacy of this drug for sheep when administered in feed.

A control group of eight ewes was selected at random, and was not treated. The remainder of the flock, 131 ewes and rams, was treated at regular intervals with phenothiazine. Treatment began in April, 1940, and continued through May, 1941, with monthly intervals between treatments. The treated sheep were separated into groups of 12 to 26 head, each according to age and sex, and were fasted for 24 hours prior to offering the medicated feed. Following the fasting period, the sheep were offered the phenothiazine mixed with ground feeds. The dose was 25 grams per adult sheep, mixed in approximately one-half pound of feed. The mixture containing the drug was fed in clean troughs, so constructed as to prevent the sheep from walking in the feed. The sheep were kept in pens until the feed was consumed. This usually required from three to fourteen hours. After eating the medicated feed, the sheep were turned out to pastures consisting of annual

crops. The animals were weighed every 28 days throughout the test, and this practice has been followed since the procuring of the flock in 1933.

Experimental Results

Gain in weight was obtained in both the treated and untreated lots during the months of April, May and June. This could be explained by the fact that green grazing, furnished by annual crops, was available and that no adverse conditions such as breeding season or lambing had been experienced during these months. In July a sudden drop in weight was experienced by both lots, the untreated lots losing slightly more weight than the treated

TABLE 1.—AVERAGE NUMBER OF INTERNAL PARASITES AND NODULAR LESIONS FOUND ON POST MORTEM EXAMINATION IN SHEEP TREATED WITH PHENOTHIAZINE AND IN UNTREATED SHEEP

Items compared	Treated lot	Untreated lot
Number of sheep	15	8
	*No. of parasites**	*No. of parasites**
Worms in the stomach:		
Wire worms (*H. contortus*)	94	14,067
Thread worms (*Ostertagia spp.*)	33	1,798
Bankrupt worms (*Trichostrongylus spp.*)	233	832
Worms in the small intestine:		
Thread worms (*Cooperia spp.*)	3,062	9,731
Worms in the large intestine:		
Nodular worms (*O. columbianum*)	8	14

* Total number of parasites observed in the entire lot of sheep examined.

group. A study of the trends in body weight revealed that during the breeding season (in the latter part of June, in July, and for the early part of August) there is always a loss in weight. Following the breeding season both lots gained in weight, and the gain was slightly greater for the untreated lot than for the treated lot. The peak of the gain was reached in October. From November to January a decided loss in weight was experienced in both lots. This was the lambing period. The loss experienced by the untreated lot was far greater than that of the treated lot. Following the lambing period, both lots made gains, but the untreated lot suddenly began losing weight and the individuals showed symptoms of parasitism. One ewe died of parasitism and it was decided to slaughter all of the untreated sheep and a representative number from the treated lot for the purpose of

making a complete post mortem examination for parasites. The results of these examinations are given in table 1.

No losses from parasitism were experienced in the sheep treated with phenothiazine. Before beginning the treatment the average annual loss from all causes was 15.9 per cent. During the period of treatment the loss was only 1.5 per cent.

Conclusions

Phenothiazine may be effectively administered to sheep in grain feed.

Doses of 25 grams per adult sheep, given at monthly intervals, are effective in controlling stomach worms in sheep.

The drug was not toxic or objectionable when given with feed.

No serious staining of the wool was observed from the use of phenothiazine.

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NEWS AND NOTES

Plans for the annual meeting in Chicago are uncertain. Transportation and other emergency conditions may make cancellation of the meetings necessary but a final decision will be delayed until September or October. In the meantime *members should plan to submit abstracts of papers, assuming the meetings will be held.* These abstracts must be in the hands of Dr. A. D. Weber, Kansas State College, Manhattan, Kansas by September 15. Please check items 5 and 6 of "Information for Contributors" and the announcement on page 174 of the May issue of the JOURNAL, before preparing your abstract. *Present plans are that abstracts will be published even though the meetings are cancelled.*

The summer meeting of the North Atlantic Branch, scheduled to be held at Middlebury, Vt., on June 5 and 6, was canceled because of the gasoline and tire situation. It now seems likely that the Eastern States Exposition will be held (Sept. 20–26) and it is planned that the regular fall meeting of the North Atlantic Branch will be held in Springfield, Mass., on September 21, 1942, at 7:00 P.M. in the Highland Hotel. The program will consist of committee reports and an address by some authority in the livestock field.

The third edition of V. A. Rice's "Breeding and Improvement of Farm Animals" was published recently by the McGraw-Hill Book Co. This edition includes 234 pages more than the second edition. Much of the material has been revised and brought up to date and considerable new material has been added.

A new text entitled "Livestock Production" by Walter H. Peters has recently been published by the McGraw-Hill Book Co. This text is written primarily for use in beginning courses in animal husbandry in agricultural colleges. It is designed to give the student a con-

cept of the scope, opportunities and problems of animal industry, and enough of the fundamentals of livestock production to form a foundation for succeeding specialized work.

H. W. Marston, formerly of the Office of Experiment Stations, has been appointed Research Coordinator in the Agricultural Research Administration of the U.S.D.A.

Beyer Aune, superintendent of the U. S. Belle Fourche Field Station, Newell, S. D., died on May 27, 1942.

The Department of Animal Husbandry at the Wisconsin University and Experiment Station has been reorganized to provide for divisions of meats and swine breeding and feeding. John M. Fargo and O. Burr Ross have been placed in charge of these divisions.

John H. Skinner, dean emeritus of agriculture at Purdue University, died suddenly while on inspection duty at one of the branch stations on April 28, 1942.

J. A. McLean, livestock feeding expert of the Quaker Oats Co., of Chicago, passed away this past spring.

George C. Humphrey of the University of Wisconsin retired from active duty in February after 39 years service.

Walter J. Peterson of the Kansas State College became head of the newly created Division of Nutrition, Physiology and Genetics, in the Department of Animal Industry at N. C. State College on May 1.

Virgil V. Parr, formerly of BAI and BAE, U.S.D.A., and for 10 years manager of the Pitchfork Ranch at Spur, Texas, is now principal soil conservationist in charge of research work in Texas for the Soil Conservation Service.

R. G. Johnson was recently made head of the animal husbandry division of the Animal Industries Department of Oregon State College.

J. A. Gorman, assistant professor in animal production, University of Wyoming, has been called to military duty.

N. W. Hilston, instructor and assistant in the Department of Animal Industry, University of Arkansas, resigned and was succeeded by Loren E. Harris, formerly of the University of Hawaii.

Dale Snodgrass, a V.P.I. graduate and former assistant county agent in Cherokee County, N. C., has been appointed assistant extension animal husbandman in North Carolina to succeed Sam L. Williams, who was called to active duty in the U. S. Army as a first lieutenant on March 11, 1942.

Thos. D. Walkins, Jr., assistant in animal industry, Montana State College, resigned to accept service in the U. S. Army.

H. H. Havner, formerly of the Extension Service of the Pennsylvania State College and more recently with a commercial feed company, is now with the livestock feed department of the Borden Co., 350 Madison Ave., New York, N. Y.

E. W. McComas of the Bureau of Animal Industry, Beltsville, Md. is on military leave and is serving in the U. S. Army.

P. A. Anderson of the University of Minnesota, A. L. DuRant of Clemson College, S. C., W. H. Tomhave, secretary of the American Aberdeen-Angus Breeders Association, W. F. LaGrange of Iowa State College, and Geo. A. Branaman of Michigan State College were members of Swift & Co.'s educational tour in April 1942.